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HUMAN ACTIVITY TRANSFORMING AND DESIGNING RIVER LANDSCAPES: A REVIEW PERSPECTIVE*

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Abstract: Where physical geography might go in the next fifty years can be contemplated from a review of how river channels have been studied in the last fifty years. The river landscape is a basis for introducing seven ways in which river landscapes have been studied and researched, culminating in an eighth holistic phase. Conclusions from studies of impacts of human activity provide a basis for suggesting that physical geographers should be more concerned with the design of river landscapes and ways in which this might be achieved are suggested.

Key words: river channels, river landscapes, river channel changes, landscape design, future physical geography.

INTRODUCTION

In view of the internationally significant research contributions made by Polish geographers it is appropriate to consider achievements in physical geography of the last fifty years to see how they can be built upon as a basis for directing attention to where physical geography might go in the next fifty years. A way of focusing our attention is to adapt the paradigm lock which was cited (Endreny 2001) as one of four obstacles to implementation of sustainable water management through the HELP (Hydrology for Environment Life and Policy) United Nations Project. The paradigm lock arises (Figure 1) because scientists (e.g. in physical geography, specifically concerned with river

channel research shown on the left of Figure 1) do not grasp what managers require; and managers and stakeholders (shown on the right in Figure 1 exemplified by River channel managers) do not appreciate what scientific alternatives are available. In modifying this paradigm lock to apply to river landscapes and to physical geography (Figure 1) it is suggested that blue skies and strategic research are integral parts of physical geography research whereas accepted practice derives from applied research and perceptions of the results of scientific research.

Hence we can consider how far the study of river landscapes and of physical geography in general can unfasten this paradigm lock in such a way as to be relevant to river channel management. To argue this case I wish 1) to consider what a river landscape is, including the diverse ways in which they have been studied; 2) to reflect on how such landscapes have been transformed by hu-

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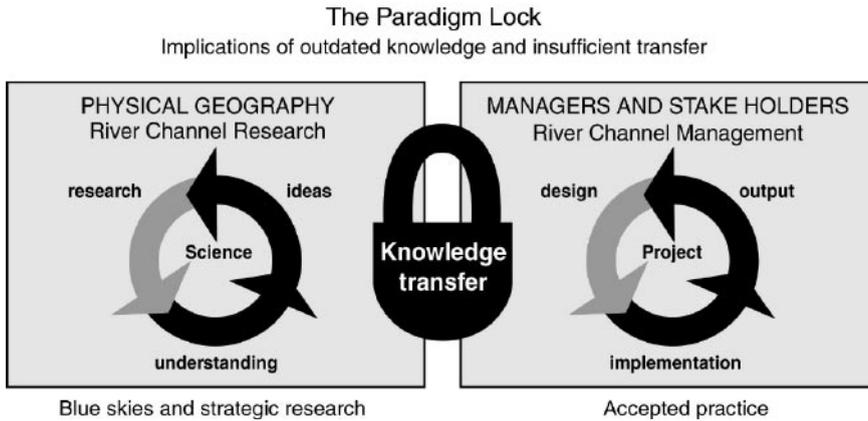


Figure 1. The paradigm lock, originally developed at a meeting in December 1998 and adopted by UNESCO (see Bonell and Askew 2000) and employed by Endreny (2001), is adapted to relate river channel research shown on the left to the requirements of managers and stakeholders (shown on the right exemplified by River channel managers).

man activity; 3) as a basis for proceeding to ask to what extent physical geographers and environmental scientists might be involved in the design of river landscapes, especially now that deliberate transformation is acknowledged to be much more of an integral part of landscape management. Examples from geomorphology have been used elsewhere to explore what happens when models meet managers (Wilcock et al. 2002), showing the importance of defining management actions where management and modelling objectives cannot be matched and also showing the utility of an adaptive modelling process in which the objectives, mechanisms and tolerances of models can be adjusted interactively in a continuing model-manager dialogue.

RIVER LANDSCAPES

River landscapes can be used to connote a way of looking at rivers in relation to the entire landscape or environment. Such a term is required because, whereas in the past there was a focus upon investigations of rivers, floodplains, river channels and reaches for example, there is now a need to focus

upon the hydrosystem (Petts and Amoros 1996) and to respond to other calls for a more holistic approach, requiring a focus which combines several of the earlier and separately identified ones such as the river corridor. River landscape has already been used as a term in the sense of components of rural and urban environments (Penning-Roswell and Burgess 1997), in relation to the river restoration and management research and development program in Australia (Brierley, Fryirs, Outhet and Massey 2002) and in relation to the leitbiliter typology of river landscapes in Austria (Kern 1992). In addition, riverine landscapes, the title for a special volume (Tockner, Ward, Kollmann and Edwards 2002), has been used 'to synthesize present understanding of the complexity and dynamics of riverine landscapes by integrating different disciplines, including aquatic and riparian ecology, fluvial geomorphology, palaeohydrology and restoration ecology' (Table 1).

The pendulum of fashion (Carson 1971) and fashion in geomorphology (Sherman 1996) is an expression of the fact that, at any one time, scientific research is conditioned by the prevailing scientific attitudes and the dominant paradigms of the day (Gregory,

Table 1. Usage of the term River Landscapes

<ul style="list-style-type: none"> • used as a term in the sense of components of rural and urban environments: ‘...river landscapes are hugely diverse, being ecologically rich habitats with a range of notable geomorphological and biological features in a rich mixture of characteristics and processes. They form recreation foci for individuals and groups, from ramblers to canoeists and from anglers to painters’. (Penning-Rowsell and Burgess 1997) • river restoration and management research and development program in Australia (Brierley, Fryirs, Outhet and Massey 2002) • river landscapes is an initiative of the Commonwealth Land and Water Research and Development Corporation. The organization coordinates the National Rivers Consortium, the Riparian Lands R & D program, the National River Contaminants Program and the National Eutrophication Management Program.http://www.rivers.gov.au/ • the leitbilder typology of river landscapes in Germany. ‘The Leitbild is a description of desirable stream properties ... based on three elements: (1) natural stream properties; (2) irreversible changes of biotic and abiotic factors; (3) aspects of cultural ecology (Kern 1992). ‘The aim must be long-term sustainable management and our vision for rehabilitation also needs to be in balance with the context of today, a feature recognised by the Leitbild (or vision) concept...(Wade, Large and de Waal 1998). • riverine landscapes, the title for a special volume (Tockner, Ward, Kollmann and Edwards 2002), ‘to synthesize present understanding of the complexity and dynamics of riverine landscapes by integrating different disciplines, including aquatic and riparian ecology, fluvial geomorphology, palaeohydrology and restoration ecology’.

2000). This is nowhere more evident than in the case of river landscapes: the perception that Yi Fu Tuan (e.g. Tuan 1992) has shown to be so significant in cultural attitudes to environment is mirrored in the way in which scientists have perceived their object of study.

Since the 1950s it is possible to discern seven ways in which river landscapes, the terrain of the environment of the river channel, have been perceived and studied, with each perception embracing different aspects of the landscape, and leading cumulatively to a current eighth perception (Table 2). **First**, in the 1950s, and prevailing for much of the first half of the twentieth century, had been the Davisian approach to rivers which employed an historic approach, and conceived rivers as part of a normal cycle of erosion in contrast to other glacial and arid cycles and to climatic accidents (see Gregory 2000, pp. 38–42). It has often been observed that, although the Davisian approach fostered the notion of landscape as a function of the trilogy of structure, process and time, there

was comparatively little real understanding of process. It is now difficult to appreciate the extent to which the Davisian approach held a stranglehold over geomorphology and the investigation of river landscapes so much that physical geography, for example in Britain (Gregory 2003a), became dominated by what was essentially a Davisian approach. This stranglehold on river research was relinquished with the impact of *Fluvial Processes in Geomorphology* (Leopold, Wolman and Miller 1964). Although this book heralded a **second** stage in the perception of river landscapes by encouraging research on river processes, there had been previous indications of the need for process investigations notably by Gilbert (1914), Bagnold (1960) and others. River landscapes were then focused very much upon the river itself and the fluid characteristics were elaborated in a series of US Geological Survey Professional Papers focussed on flood plains and channel patterns for example. Process investigations necessarily required greater

appreciation of the controls upon hydrology and this effectively led, **thirdly**, to a perception of rivers in the drainage basin system acknowledging the importance of hydrology (e.g. Gregory and Walling 1973), which had benefited from and is paralleled by a number of investigations of the Columbia school (Strahler 1992) and of the drainage basin as the fundamental geomorphic unit (Chorley 1969). Such developments were contemporaneous with the advent of systems thinking in the environmental sciences and with the increased use of modelling so that, **fourthly**, river landscapes became elaborated as components in increasingly sophisticated and often mathematical models (Anderson and Burt 1985; Kirkby 1994). **Fifthly**, the perception of river landscapes influenced by

human activity emerged during the 1970s, founded upon influential papers showing how rivers could be affected by urbanization and land use changes (Wolman 1967a) and by reservoirs and flow regulation (Wolman 1967b). Subsequent investigations did not always acknowledge the fundamental proposal of Lane (1955), a hydraulic engineer, who focused on the ways in which river channels could adjust in response to alterations of flow or sediment transport, in fact paving the way for later analyses of degrees of freedom (Hey 1982) and of adjustments of river systems (Gregory 1977; Gurnell and Petts 1995). The theme of evolution of river systems and their change over time had continued after Davisian approaches, with studies of river terraces and valley chronol-

Table 2. Progress of scientific perception of river landscapes

Subject or theme	Focii developed	Terms	References
River in a cycle of erosion	River evolution, graded profile, stages of development	Youth, maturity, old age	Davis (1899)
River processes	Hydrology Sediment and solute dynamics	Hydrographs Suspended sediment hydrographs Sediment and solute budgets	Gilbert (1914), Bagnold (1960), Leopold, Wolman and Miller (1964)
River in the drainage basin	Drainage basin unit Systems analysis Channel and network dynamics Channel and network dynamics	Drainage network analysis, Stream ordering methods Drainage basin characteristics	Chorley (1969), Gregory and Walling (1973), (Strahler, 1992)
River modelling	Hydrological models	Contributing areas Thresholds	Kirkby and Chorley (1967), Kirkby (1978)
Human impact on rivers	River metamorphosis Thresholds Complex response	Channel adjustment Enlargement ratios	Wolman (1967a, b)
Paleohydrology	Multidisciplinary research	Underfit streams Paleofloods	Schumm (1965, 1977); Gregory (1983)
River management	Soft engineering methods Sustainable approaches	River restoration Design with nature	Gore (1985); Brookes and Shields (1996); Thorne, Hey and Newson (1997)
Holistic Approach	River landscapes	Management with nature	Downs and Gregory (2004)

ogy, but became a significant influence, **sixthly**, with studies of palaeohydrology (Schumm 1965; Gregory 1983) later reinforced by stimulating advances for example by use of radioactive markers in relation to floodplain history by Walling and others (e.g. Walling and He 1999).

It is of course artificial to suggest that these six sequential phases were clearly distinct but there is no doubt that a succession of approaches have been compounded, thus affecting the way in which the river landscape has been perceived, and therefore investigated and researched. This influence upon the research framework has been evident particularly through the way in which different time and spatial scales associated with each of the phases have been adopted. The characteristics of the six phases of perception, including the time and spatial scales to which they have referred, and the associated generation of landscape terms are listed in Table 2.

Such phases remind us how, at any one time, scientific perception of a subject of study is time-dependent and that other perceptions will follow in the future. The **seventh** phase, at the beginning of the 21st century is necessarily a culmination of earlier ones which may be seen as an integrated perception of a river system that has to be managed, recognising what we have learnt from past development. Not all scientists agree about the culmination of a progression through different phases (Table 2) leading to a cumulative advance; it has been suggested that Davis was the only really effective fashion (Sherman 1996) including fashion dudes instanced by Davis, Gilbert, Strahler and Chorley; or alternatively that fluvial geomorphology needs to address major questions (Smith 1993) including 'Either the field stays in its current operational mode and becomes a backwater science, or it moves forward and adopts the ways of the more competitive sectors of the earth and biosciences' (Smith 1993, p. 251). At the end of any sequence of perceptions in science there must be a prevailing view which is the culmination of earlier views, connoted as the **eighth** perception in Table 1 as Holistic.

Retrospectively it is now amazing to reflect that the way in which we study river landscapes has been completely metamorphosed during that half century and it is possible, with hindsight, to see how a number of formative phases has cumulatively given a foundation for a 21st century approach. In that half century the nomothetic approach succeeded the idiographic with a search for the general rather than the particular. It is interesting to note that in the early 21st century there is already recognition that generalizations and modelling are not the only objectives because the importance of place is being recognized once again (Phillips 2001), addressed by contingency. Of four possible interpretations, that of dependence is most pertinent in physical geography so that Phillips (2001) argued that 'it is necessary to acknowledge the historical and spatial contingency of places'. Historical contingency means that state of systems or environment is at least partially dependent on one or more previous states or on events in the past. Where the state of a given feature is uniquely dependent on local history or on a specific past event, this occurs as a result of inheritance (inherited from parent material or previous environmental regimes that differ from contemporary environment) and conditionality (when earth surface system might proceed along two or more pathways according to whether, or at what intensity, a particular phenomenon occurs).

TRANSFORMATION OF RIVER LANDSCAPES BY HUMAN ACTIVITY

In the 21st century it is difficult to appreciate that effective study of the impact of human activity upon river landscapes is little more than three decades old. Although the direct impact upon rivers had been appreciated qualitatively it was only after the late 1960s that the indirect consequences of human impacts began to be recognized, unleashing a number of research investigations dedicated to establishing the quantitative consequences of human activity upon river

landscapes. Direct impacts upon processes were apparent and acknowledged in engineering management to avoid scour below dams or flood problems in urban areas, employing protection to mitigate the first and flood control schemes to distribute the second further downstream.

The magnitude of process changes has been appreciated and, with the benefit of hindsight, surveying the research over the last three decades it is now possible to discern the major types of impact caused by human activity as indicated in Table 3. Building on the work achieved on the effects of human activity it is possible to distinguish five issues:

- Direct impacts
- Indirect impacts
- The consequences of these impacts for river landscapes
- Interaction of changes and relation to global change
- The choices which arise—what should we do about them?

Direct impacts of human activity include two main categories: first those whereby there is a direct impact on the river landscape such as channelization of reaches,

dam construction and other engineering structures and, more recently, the effects of dam removal (Downs and Gregory 2004); second the effects upon river channel processes have been documented in numerous studies showing that, downstream from urban areas, peak discharges may be increased by up to 3 to 4 times (Walling 1987; Choi, Engel, Muthutrishnan and Harbor 2003) and, downstream from dams, flow regulation may mean that flows are greatly reduced and sometimes completely eliminated, so that for example less than 1% of Colorado virgin river flow reaches the delta (Petts 1994), and the Huang He flow may cease in the lower reaches (Liu Changming 2000). Associated changes in sediment discharge and water quality are also included in this direct category.

It is such direct changes in river landscapes and their fluvial processes that instigate a number of **indirect impacts** on the channel. As a result of studies during the last 3 decades (Gregory 1995) it is now evident how such impacts can arise and how extensive they can be (Table 3). Such indirect impacts are exemplified downstream of urban areas where the increased flood flows

Table 3. Allogenic changes over the basin that may cause river channel changes. (Developed from a table by Gregory and Walling 1973. See also Downs and Gregory 2004)

Causes	Direct impacts on processes H—hydrology, S—sediment	Indirect impacts on channels L—local; E—extensive	Some consequences for river landscapes
CLIMATE OVER THE BASIN			
Greenhouse effect including thermal pollution, increased CO ₂ , CO, NO ₂	Varies with area		New pattern of flows, especially of peak flows, may affect river channels
Cloud seeding	H+	L	
Increased storminess	H+	L/E	
VEGETATION AND LAND USE CHANGES			
Deforestation	H+ S+	L	Gulleying may occur in some areas
Grazing	S+ H+	L	
Fire, burning	H+ S+	L	
Agriculture, ploughing	H+ S+	L/E	

Land use, conservation measures	H- S-	L/E	
Afforestation	S- H-	L/E	Flows should be reduced but drainage lines may still be influential
Building construction	S+ H+	L	
Urbanization	H+ S-/+	L/E	Road drains complement drainage network
Drainage schemes	H+/-	L/E	
Agricultural drains	H+/-	L/E	Water table effects
Irrigation networks	H+/-	L/E	
Stormwater drains	H+	L/E	May replace surface channels
CHANGES AFFECTING RIVER CHANNEL			
Desnagging and clearing	S+	L	
Clearance of riparian vegetation/tree clearance	S+ H+	L	Local channel adjustments may occur
Sediment removal, mining gravel extraction	S+	L/E	
Sediment addition, mining spoil	S+	L	Changes in sediment transport may affect channel
Boat waves, bank erosion	S+	L	
Invasion by exotic vegetation species	S-	L/E	
Restoration and allied techniques	H- S-	L/E	
Channelization		E	
• Bank protection and stabilization	H+ S-	L/E	Changes in channelized reaches and downstream may be complex and occur
• Resectioning, dredging	H+/- S-	L/E	for time period depending
• Channel straightening, cutoffs	H+	L/E	upon local characteristics
Embankments and levees	H+	L	
Diversion of flow, leats, HEP	H-	L/E	
Dam construction	H- S-/+	L/E	Changes of channel—
Weirs	H- S-/+	L	forming flows may affect
Abstraction of flow	H-	L/E	channel morphology and
Return flow, drains, outfalls	H+	L/E	also influence sediment stability
Bridge crossings	H+	L	Local scour may occur
Culverts under roads and crossings	H+	L	Channels may be segmented by stormwater entry points

and the reduced sediment concentrations may induce larger channels or sometimes increased channel erosion, and different patterns of floodplain inundation. Conversely, downstream of reservoirs the reduced peak discharges and sediment concentrations have often occasioned a shrinkage of channels, with possible change from multithread to single thread channels, often with ecological consequences. At first it was assumed that there would be a general model which could be identified and would hold the key for the understanding and subsequent management of changing river landscapes. However, control upon adjustments by the environmental characteristics of particular areas became increasingly evident, complex response (Schumm 1977) as exemplified by studies of channels downstream of reservoirs in the US (Williams and Wolman 1984) demonstrating that there were no uniform adjustment characteristics, thus refocusing attention on specific places and contingency analysis as suggested by Phillips (2001, 2003). Studies of **why** changes occurred (Table 3) and of **what** effects resulted prompted other questions including (Gregory 1987):

- **where** changes occurred depends upon proximity to thresholds. However, there are variations, not only from one area to another but also along a particular river (e.g. Graf 2000). In some areas direct and indirect impacts have been responsible for subdivision of river landscapes into segments (e.g. where reservoirs interrupt river systems or where urban areas create distinctive systems with new stormwater inputs (see Downs and Gregory 2004).

- **how** changes were effected—increased peak flows can instigate channel erosion and enlargement, or induce more frequent inundation of the floodplains. Thus in Australia the alternation of drought-dominated and flood-dominated regimes (Rutherford 2000) is a type of sequence which may be repeated, albeit in a different response, elsewhere.

- **when** changes began and when did they stop? Some changes when instigated may require a major flood event before changes begin to impact. Also there is a se-

quence of change, graphically expressed by the rate law (Graf 1977) which demonstrates the reaction time before change begins, followed by a relaxation time during which adjustment occurs; then there is the question of how long adjustment will take. We still do not know enough about relaxation times in different areas and with different impacts.

Such changes of river channels meant that attention had to be given to **consequences of these impacts for river landscapes** and when the why, what, where, how, and when questions were considered it was evident that it was not easy to guess what impacts would occur in any particular area. Such uncertainty was why it was suggested that there are 10 reasons to be wrong (Schumm 1991). Thus channel narrowing in south east France occurred in response to land use changes (Liebault and Piegay 2002). An excellent example is potentially provided downstream of urban areas: increased runoff from urban areas means that increased flooding can occur downstream, often with serious consequences. However, increased flows mean that channel-forming flows are greater so that channel dimensions may adjust in such a way that they can contain the increased discharges. Such development was not appreciated for many years despite an early paper by Riggs (1978) and, in effect, can condition the way in which channel adjustments should be approached.

A further consequence of river channel adjustments is that in many areas there is not one but multiple causes, with **interaction of changes** in the hydrosystem on top of which the impact of **global climate change** may be superimposed. Arising from palaeohydrological studies it has transpired (Starkel 2001, 2003) that events of particular magnitudes may be clustered in the palaeohydrological record. This means that, if there are changes in frequency of occurrence of events of particular size, then after such magnitude and frequency changes, there can be significant alterations in river channels and in river landscapes. There has been some speculation about the impacts of global change on river channels (e.g. Newson and Lewin 1991), and on river landscapes, but further analysis is required.

An outcome of three decades of research on river channel change has been greater appreciation that such changes are much more widespread than were originally supposed, that they are complex and interact in ways which are particular to the character of the basin environment, so that they have implications for **choices that arise and what we should do about them**—the ways in which river landscapes are managed. Such conclusions accord well with the way in which thinking has progressed towards a holistic catchment framework for river channel management. Management has progressed from the technology can fix it philosophy (Leopold 1977) towards the notion that softer engineering methods should be employed wherever possible and that management of reaches of channel and river landscape should be undertaken in the context of a dynamic holistic approach to the catchment or drainage basin as a whole.

DESIGN OF RIVER LANDSCAPES

Research on river channel adjustments therefore raises further questions, including that of how such knowledge can contribute to river channel management and to the management of river landscapes. Management essentially embraces, both implicitly and explicitly, the design of river landscapes, and poses the question as to what extent the physical geographer or environmental scientist should be interested in, and should extend their research to, the question of river landscape design, thus attempting to open the paradigm lock (Figure 1). Not everyone agrees with the notion that the physical geographer could be more involved in environmental design (Gregory 2000): for example it has been suggested (Bishop 2003) that many physical geographers quite simply do not wish to become involved in the cultural side of physical geography and in the interaction between the human and physical environment. However, as river landscapes are increasingly visualized in terms of restoration and softer management techniques requiring design, then for a physical

geographer or environmental scientist to be involved in such design procedures does not presume an eclectic super scientist but rather one who is a distinctive geographical member of a multidisciplinary team, contributing knowledge of evolution of river channel systems and of the mechanics of river landscapes. Indeed, as physical geography and environmental science evolved to embrace greater investigation of processes, of the impacts of human activity, and the effects of recent evolutionary changes, it is arguably a logical extension of previous research to become concerned with applications—and a prime application is the design of river landscapes. Although nature can be managed without science—by trial and error and folklore—in order to be effective river management requires the improved application of environmental sciences—hydrology, geomorphology and biology (Calow and Petts 1992).

There are antecedents for a physical geographer's interest in landscape design. In *Traces on the Rhodian Shore*, (Glacken 1967) it was suggested that God's design had been replaced by Nature's design, being in turn (Chorley 1973) supplanted by Man's design. The roots of the movements leading to a 'design with nature' approach can be traced to Europe in the mid 19th century (Petts, Sparks and Campbell 2000). However, efforts were very sporadic until the mid 1960s when awareness of the need for an alternative to hard engineering encouraged a general movement towards a softer management approach which included restoring the landscape to a more 'natural' character. One might have expected such progress to be a concern of the earth and environmental sciences, but it was the disciplines of landscape architecture and ecology that became most significantly involved. The ideas of the landscape architect Jens Jensen at the University of Chicago, of Aldo Leopold, who advocated a land ethic which 'changes the role of Homo Sapiens from conqueror of the land-community to plain member and citizen of it' (Leopold 1949), and others at the University of Wisconsin in the 1930s, were influential (Berger 1990). However,

a landscape architect at the University of Pennsylvania, Ian McHarg (1969), in his book *Design with Nature*, proposed ideas of significance beyond landscape architecture itself. The ideas were first developed in respect of the city where it was suggested in 1964 (McHarg and Steiner 1998) that an immeasurable improvement could be ensured in the aspect of nature in the city, in addition to the specific benefits of a planned watershed. *Design with Nature* provided a method whereby ecology was used to inform the planning process, and the intent and language used subsequently appeared in the 1969 National Environmental Policy Act and in other legislative instruments in the USA. Landscape architects such as McHarg (1969, 1991) were, therefore, prominent in envisioning an ecologically-based planning approach for landscape, to match ecological analogies already offered in the innovative building architecture of Frank Lloyd Wright (Smith 1998) and those used in art and aesthetics (Tuan 1993). Reflecting on the way in which *Design with Nature* evolved (McHarg, 1996) it is evident that although a general ecological foundation was influential, there was insufficient input from hydrology, geomorphology and the branches of physical geography. This was unfortunate for physical geography but inevitable because the necessary progress, for example on the themes considered above (Table 2) had yet to be completed. However, McHarg (1996, p. 91) notes in retrospect that 'geography and the environmental sciences were conspicuously absent', and that there was 'a general conclusion that geomorphology was the integrative device for physical processes and ecology was the culminating integrator for the biophysical. These contributed to understanding process, meaning and form' (McHarg 1996, p. 331).

Aspects of design are certainly implicit, if not explicit, in several of the strands of research undertaken by physical geographers (Gregory 1992). Thus investigations of river channel change led to suggestions of implications for management as in urban landscapes of arid areas (e.g. Chin and Gregory 2004). Restoration approaches (Brookes

and Shields 1996) are not the exclusive province of the physical geographer because ecologists (e.g. Gore 1985) and engineers, through ecological engineering (Mitsch and Jorgensen 2004), have made very significant contributions but there have been specific contributions by physical geographers (e.g. Sear 1994) and design has been included as one of four key areas in which fluvial geomorphology provides management information (Kondolf, Piegay and Sear 2003) although this was confined to channel design (p. 647). This requires ethics to be applied to landscape and not only have human geographers contributed to this field (e.g. Smith 2000) but there have also been contributions from a physical landscape perspective (Reed and Slaymaker 1993), together with recognition that physical geographers involved in the conservation of rivers have to be cognizant with political, cultural and legal frameworks (Boon et al. 2000).

Although design with nature approaches can focus upon environment as a whole, rivers provide a particular focus; indeed they have been graphically portrayed as sentinels serving as the continents circulatory systems, so that study of their biology, like the study of blood, can diagnose the state of health not only of the rivers themselves but of their landscapes (Karr 1998). Within geography a central weakness of response to environmental problems and to issues of sustainability is the lack of engagement with questions of ethics; furthermore, it has been suggested that the growth of geomorphology as a practical profession requires that geomorphologists continue to devote effort to developing and refining a design science to support this profession (Rhoads and Thorn 1996, p. 135). Rhoads and Thorn (1996) argued that such a design science can provide the basis for professionalization of the discipline by codifying a body of information, tools and skills for licensing or certification of programs.

What are the areas where design with nature has already been applied in physical geography and where could it be applied in future, so that physical geographers and en-

Table 4. Elements of design of river landscapes of interest to physical geographers (Developed from tables in Gregory 2003b; 2004, Downs and Gregory 2004)

Major element	Requirement involved
Context	<p>The basis for an approach</p> <ul style="list-style-type: none"> • <i>The importance of place</i>—the strategy devised for any river landscape should be constructed with awareness of the particular channel and its spatial environmental context • <i>The implications of scale</i>—Use catchment-scale solutions integrated, basin wide planning, and a holistic approach for channel and flood management; and to describe and formalize the problem of ecological restoration at the catchment scale • <i>Situation in time</i>—reference to the temporal position in its sequence of development, Consider any detectable phases in the palaeohydrology or sediment budget record to set the management period into a temporal pattern • <i>Consider historical context and sensitivity to change</i> • <i>Employ a sustainable approach</i> • <i>Understanding the Past and the Present</i>—in the context of what is nature • <i>Work with nature and not against it</i>, emulating nature in river designs; restore environmental (habitat) heterogeneity but letting the river do the work; <p>Environmental assessment</p> <ul style="list-style-type: none"> • <i>Use as much historical data</i> on floods, flood hazard and flood mitigation measures and channel behaviour as possible • <i>Consider hazards created by erosion and sedimentation</i> together with those of flood discharges, with structures designed for high sediment loads • <i>Take into account high spatial and temporal variability</i> of floods and flood impacts, and their feedback effects • <i>Select the appropriate time scale for channel management</i>, augmenting the continuous record as necessary • <i>Include awareness of the period of records</i> used as the basis for previous channel management decisions <p>Outline planning</p> <ul style="list-style-type: none"> • <i>Use integrated, basin wide planning</i>, and a holistic approach for channel and flood management to describe, formalize and envision ecological restoration in a catchment scale strategy • <i>Consider any detectable phases in the palaeohydrology or sediment budget record</i> to set the management period into a temporal pattern—Raise awareness of the period of records used for making earlier channel management decisions • <i>Acknowledge the cultural context</i>—cultural differences between countries and regions require differential responses to river channel management challenges • <i>Consider the political framework</i>—together with requirements for legal implementation • <i>Ensure that institutional organization and structures are sufficiently flexible</i> • <i>Stress the uncertainty of predictions</i>, giving scientific results to decision makers as a range of possibilities and probabilities with consequences of extremes indicated • <i>Adopt a basin perspective</i> by identifying reaches and segments of channel that are unstable, sensitive, as a result of mitigation or management measures or human activity including those that may become sensitive in the future;
Implementation	<p>Reviewing alternatives</p> <ul style="list-style-type: none"> • <i>Utilize a basin framework</i> to identify homogeneous reaches requiring similar management activity reaches and segments of channel that are unstable/sensitive, as a result of mitigation or management measures or impact of human activity, including those that may become sensitive in the future • <i>Set the pattern of sensitive reaches in a dynamic basin context</i> by taking account of changes in sediment history including phases of storage and exhaustion • <i>Assessment techniques</i>—identify <i>Use environmental condition of reaches to select approaches</i>—based on principles of: preservation and natural recovery, restoring flow and sediment transport, prompted recovery, morphological reconstruction, and instability management • <i>Adopt non-structural and do nothing approaches wherever possible</i>, using procedures that have least damaging environmental impacts

Table 4 *cont.*

	<ul style="list-style-type: none"> • <i>Work with nature and not against it</i>, emulating nature in river designs; restore environmental (habitat) heterogeneity but let the river do the work • <i>When restoring channels give careful consideration to:</i> <ul style="list-style-type: none"> Is restoration feasible for the particular channel? Is restoration to be to a more natural state or to some specific prior condition and if the latter what is the basis for the decision? Does the restored state present the most stable channel which will avoid impacts downstream or upstream? Consider 'natural' in any area as a social construct which must be negotiated with the local community giving opportunity for education of that community in relation to palaeohydrology • <i>Ensure that the scheme implemented is as sustainable as possible</i> and capable of adaptive modification • <i>Rationalizing risk to support decision-making</i>—assessment of the risks involved • <i>Management with Stakeholders</i>—including formulation of shared visions, and stakeholder education • <i>Set priorities in relation to competing claims, statutory obligations</i> • <i>Employ a detailed appraisal process</i>, consult widely, considering all the environmental issues at the range of appropriate scales alongside the engineering and economic objectives;
Effecting the design	<p><i>Catchment scale approach to design with nature</i> including:</p> <ol style="list-style-type: none"> 1. catchment and corridor policies <ul style="list-style-type: none"> • catchment based policies • corridor based strategies 2. methods for improving network connectivity <ul style="list-style-type: none"> • environmental high flow releases • reconnecting backwater channels • weir removal • large dam removal 3. in-stream measures <ul style="list-style-type: none"> • instream structures • recreating local bedforms • cover devices • sediment traps 4. channel reconstruction, 5. methods for reinforcing the channel perimeter <ul style="list-style-type: none"> • bed protection • bank protection
Post project consideration	<p>Keep areas under review by Adaptive ecosystem management including</p> <ul style="list-style-type: none"> • <i>Undertake post-project appraisal</i> so that knowledge about impacts of river management continues to grow • <i>Incorporating Future Conditions</i>—including managing natural recovery and created environments and developing improved predicted models • <i>Coping with Uncertainties: the culture of management</i>—requiring adaptive management and education of river managers • <i>Ensure proactive involvement of the range of management bodies</i>

environmental scientists can contribute to the design of river landscapes? We can envisage a number of topics which might be the basis for future contributions and these arise from 'principles' of river channel management (Gregory 2003b). Although there have hitherto been comparatively few explicit statements of principles to guide river managers or to express the way in which river

management is undertaken, the sets of principles suggested by several previous workers (see Gregory 2003b) can be developed to provide principles of river channel management including palaeohydrological inputs (Gregory 2004). Combining and developing these suggestions and incorporating dimensions of pluralistic river management, rudiments of channel management with

nature and requirements for designing river channels (Downs and Gregory 2004), it is possible to construct a tentative outline for ways in which physical geographers can be concerned with design of river landscapes. Such a tentative outline is offered in Table 4 to include, first, *expressing the context* which includes the basis for an approach, environmental assessment and outline planning; second *implementation* which necessarily involves consideration of alternatives for any particular river landscape; third *suggesting a design* which requires knowledge of techniques and their relative merits; and fourth *post-project considerations* which are ongoing after the project is implemented.

This approach is proposed to stimulate thinking about the future role of physical geographers in relation to river landscapes with implications which extend previous general management approaches. We have outgrown the idea that there can be a polymath applied physical geographer and now need to think about precise ways in which a physical geographer can contribute to the future design of river landscapes, often as a member of a multidisciplinary team. This may at first seem to be fairly radical and to stretch physical geography further than previously, but surely we need to challenge and extend existing approaches and to think creatively. Thus, in an analogous way, instead of thinking about ecosystems as physical objects, they have been visualized in terms of attributes with value for people as natural assets or 'natural capital'—an approach employed by Haines Young (2000) to combine the scientific and cultural traditions of landscape ecology in managing landscapes, providing an understanding of how the physical and biological processes associated with landscapes can have value in an economic and cultural context (Haines Young 2000).

CONCLUSION

River landscapes are increasingly recognized as a focus for research (Table 1) and their study has progressed through series

of stages (Table 2). We need to learn from the cumulative knowledge provided by these stages and from the lessons which continue to be learnt from existing approaches (Table 3). One example of how existing approaches are extended is the diagnostic approach to stream channel assessment and monitoring that has recently been proposed (Montgomery and MacDonald 2002) and is analogous to medical practice. However, in addition to such extensions of each of the component approaches used in the investigation of river landscapes, we also need to consider how our holistic approach might be developed. This paper has argued that it is entirely appropriate that, succeeding the detailed research of the last fifty years, it is now timely to benefit from the foundation which has been provided by extending the interest of physical geographers to the design of river landscapes and to landscape design in general. This will not be achieved by physical geographers alone but by their *research* and application as integral members of multidisciplinary teams. The design and management of river landscapes should then be more explicitly approached in the next 50 years to follow from the implicit, and rather incidental, approach that has been evident as an increasingly emerging characteristic of the last 50 years.

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LARGE-SCALE TRANSECT STUDIES AND THEIR USE IN THE INVESTIGATION OF CLIMATE EFFECTS ON CARBON STORAGE IN FOREST ECOSYSTEMS*

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Abstract: The development of large-scale transects in ecological studies has provided a new tool for investigating ecosystem behavior under changing climate. These studies do not replace experimental research, but provide a complimentary tool that substitutes space for time in the investigation of complex ecological responses that cannot be easily examined in controlled experiments. Examples of two large-scale transect studies are described, and selected results regarding the allocation of C within ecosystems in response to climate are highlighted.

Key words: global change, transect studies, gradient studies, carbon cycling.

INTRODUCTION

Environmental concerns have become more global in scope, and often transcend national boundaries. Methods of studying the impacts of environmental changes need to produce results as soon as possible, and need to be as definitive as possible in order to catalyze action by policymakers. Such methods often require international collaboration, not just because of the large extent of the impacted areas, but also to facilitate the development of an international consensus among the scientific community to inform the policy debate.

The objectives of this paper are to: 1) present the technique of large-scale transect

studies, describing their development in recent years and situations where they are appropriate; and 2) to illustrate the utility of large-scale transect studies in the investigation of climate impacts on carbon cycling in European forest ecosystems.

LARGE SCALE TRANSECT STUDIES

Ecological transect studies investigate the ecological impacts of an environmental factor, such as moisture availability or elevation, by studying ecosystems that can be found under different levels of exposure to the environmental factor. The goal is to hold as many environmental factors as possible within relatively narrow bounds in order to magnify the ecological signal due to the environmental factor of interest and to increase the chances of detecting any resulting ecological effects.

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Until the 1980s, most such studies had been over short, well defined transects. Examples include investigations of plant community composition in a riparian zone at different distances from a waterway, or studies of plant community composition at different

transect ranging from the Arctic Circle in Scandinavia to northern continental Europe. Another example is illustrated in Figure 1, showing a transect of forest plots along climatic and pollution gradients extending from near Berlin to the eastern border of Belarus.

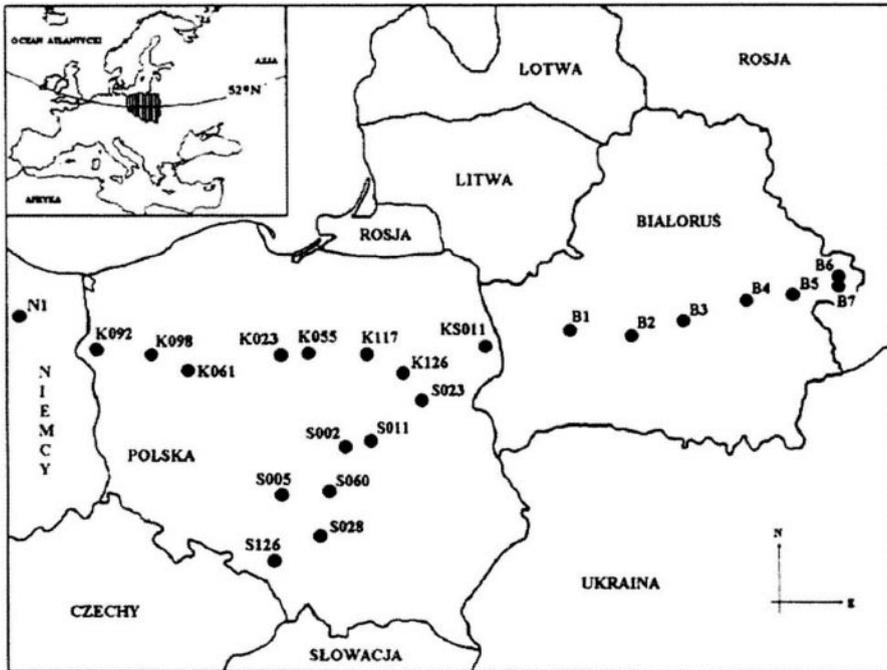


Figure 1. Climate and pollution transects extending from near Berlin to eastern Belarus (adapted from Degórski 2002).

elevations in a mountainous region. Bordner (1942) investigated secondary forest composition along a 200 km transect, cited to be of 'record-breaking length' by Curtis (1959).

In the 1980s, transects of much larger-scale began to be used to investigate environmental factors like acidic deposition or climate. Burton et al. (1991) report results from a study investigating foliar leaf area and biomass along an 800 km acid deposition gradient. Using field data collected at about the same time, Johansson et al. (1995) investigated rate-regulating factors for decomposition of Scots pine litter over a 2000-km

This last transect is described in greater detail by Brey Meyer (1997).

Such large scale studies require the careful selection of study sites. It is important to insure that major factors, like soil morphology, vegetation type, overstory age and structure, etc. are analogous among the study sites, and that the main environmental difference is the factor being studied, such as pollutant deposition. This often requires collaboration with local experts, which can sometimes be difficult to coordinate. It also often requires extensive travel by measurement crews to insure that exactly the same

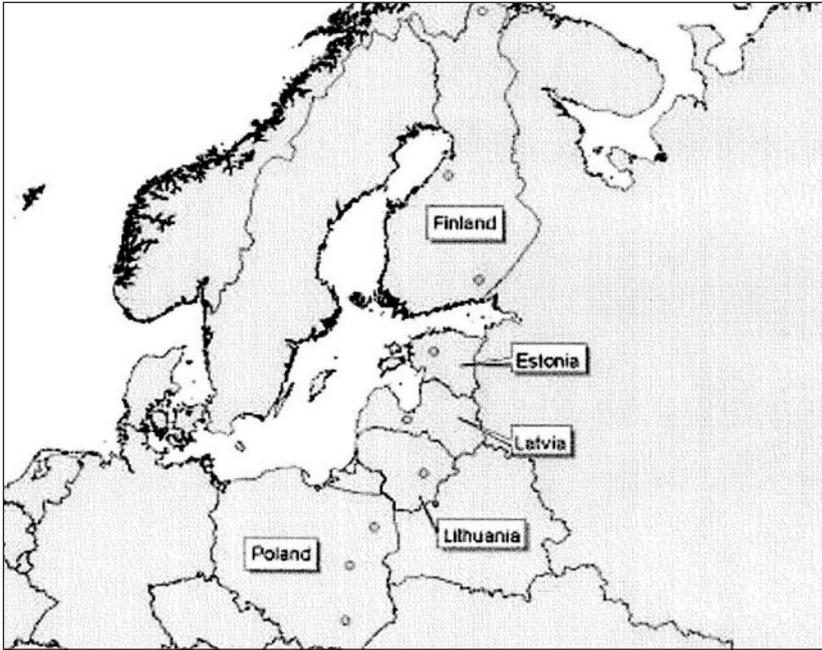


Figure 2. Locations of nine study sites along the temporal to boreal transect in Poland, Lithuania, Latvia, Estonia, and Finland.

measurement methods are utilized at all sampling locations. Data quality assurance and quality control are primary concerns that must be addressed in order to have comparable results.

The underlying idea behind large-scale transect studies is that through careful site selection, the studied systems substitute space for time in the investigation of the environmental factor of interest. In other words, by investigating ecosystems developing under different environmental conditions, it is possible to infer how a given system will respond to environmental change such as that possibly induced by factors such as acidic deposition or global change. The necessity of a policy response means that it is often not possible to realistically investigate such changes through experimental manipulation because: 1) it may be impossible to realistically manipulate a system to emulate the factor of interest; and 2) it may take so long to observe responses following such

manipulation that such an approach cannot meaningfully inform a policy debate.

Transect studies do not substitute for controlled experimental studies. Rather, transect studies and controlled experimental studies are complimentary, in that transect studies can quickly confirm or reject hypotheses investigated in controlled experiments. Controlled experiments, in return, can rigorously confirm or deny relationships observed in large-scale transect studies. Science, therefore, can advance more rapidly through utilization a variety of methodologies to investigate complex, but globally significant environmental issues.

INVESTIGATING CLIMATE IMPACTS ON CARBON STORAGE IN FORESTS

Northern forests are critical components of the global carbon cycle. Dixon et al. (1994) indicate that *c.*25% of all terrestrial above-

ground C and c.60% of all terrestrial below-ground C are in the 1.4 billion hectares of forests at high ($> 50^\circ \text{N}$) latitudes. The interaction of climate change with C pools in high latitude forests is particularly important to understand because climate change is expected to be greatest at these high latitudes (Houghton et al. 1996; Rind 1999).

Globally, between 98 and 99.7% of the total forest area is sequestering C, and between 0.3 and 2% is emitting C, but C uptake and emissions approximately balance (Prentice et al. 2000). In Europe, the terrestrial biosphere absorbs 7–12% of European anthropogenic CO_2 emissions. Of this though, forests and wooded areas absorb 377 Tg C yr^{-1} , while all other terrestrial systems emit 98 Tg C yr^{-1} (Janssens et al. 2003). Alteration of C cycling in northern forests in response to climate change could have dramatic impacts on both global C cycling and the European C budget.

To investigate potential climate change impacts in northern European forest C storage, a large-scale transect of nine sites (Figure 2) was established from southern Poland (50°N) to northern Finland (70°N). Information on study site selection and site descriptions can be found in Vucetich et al. (2000), and in greater detail in a recent special issue of the Polish Journal of Ecology (Reed et al. 2003 and associated papers).

Reed and Nagel (2003) describe dramatic differences in the distribution of C within ecosystems along this transect. In the north, there is a much greater proportion of total ecosystem C in soil organic horizons (58%) than in the south (24%). In addition, there is a much lower proportion of total ecosystem C stored in overstory tree biomass (5%) in the north than in the south (24%). Taken together, these findings indicate that there is a long-term possibility of increased C sequestration in northern forests under a warming climate due to an increase in overstory biomass in response to warming. In the short term though, there is a possibility that these systems could become a source of atmospheric C through increased decomposition, possibly tipping the balance

in these systems to a net C emission in the near term. This would provide a feedback loop that could increase atmospheric CO_2 concentration over the time span of years to decades, while leading to an increase in ecosystem C sequestration over a time span of several decades to centuries.

There is still much to be learned about decomposition. Schadt et al. (2003), for example, recently found that soil microbial biomass reaches its annual peak in the late winter under snow cover in Alpine tundra systems, and that there is a shift in the microbial community from bacterial dominance in the summer to fungal dominance in the winter. Using the large scale transect shown in Figure 1, Breymer et al. (1997) demonstrated complex interactions between heavy metal deposition, climate, and decomposition. Such interactions would not be identified in controlled experiments, but require ecosystem-level observations to become apparent. Large-scale transect studies provide the means to identify complex interactions among environmental factors in natural ecosystems.

CONCLUSIONS

Large-scale ecological transect studies provide an alternative experimental method that compliments controlled experiments. Large-scale studies can provide verification of results from controlled experiments, and can also serve to generate hypotheses to be tested under controlled conditions. Transects at these large scales were first implemented in the 1980s and have clearly demonstrated their utility in addressing complex environmental problems since that time. They have been particularly useful in addressing questions concerning the ecological impacts of environmental pollution and in identifying possible ecological impacts under potential climate change scenarios. This knowledge can be extremely useful in the design and establishment of monitoring efforts and in guiding experimental studies to support environmental policy decisions.

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THE IMPORTANCE OF PARALLEL STUDIES ON PAST AND PRESENT-DAY ENVIRONMENTAL CHANGE*

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Abstract: The parallel study of past and present-day environmental changes helps in the better understanding of the relations between processes, their effects, and the long-term trends to them as well as in the recognition of the relations between various temporal and spatial scales. The author characterizes two means of deduction: from processes to effects and in the opposite direction. Especially valuable are studies on the last centuries, in which all groups of methods may be used simultaneously.

Key words: parallel study on past and present, environmental changes, processes, long-term trends.

INTRODUCTION

Studies on past and present-day changes are usually running in parallel being conducted by various teams, or even by representatives of different disciplines. It would seem more fruitful to have parallel observations in these two fields carried out by one and the same team in regard to the mechanisms of processes *in statu nascendi* through their monitoring, and in regard to their effects and products over longer time scales of the past. Such bidirectional research may help us to better understand the relations between processes, the effects thereof and the long-term trends thereto, as well as to recognize the relations between various

temporal and spatial scales (Starkel 1999, Figure 1). The course and effects of these processes on the local scale can be better understood when being presented against a wider regional background and correlated with global mechanisms. On the other hand, the global or continental trends to changes registered by modern techniques like satellite monitoring, or reflected in the shifting of zonal ecosystems like the expansion or melting of ice sheets, may be exemplified by the stationary (local scale) measurements of cycling of matter and energy exchange or by the geological records well preserved at the key sites. Therefore the whole range of spatial and temporal scales (Figure 1) should be taken into consideration when studying environmental changes. Such a bimodal research programme has been put into practice via the activity of the Department of Geomorphology and Hydrology... in Cracow (Starkel 2003b). Most of the

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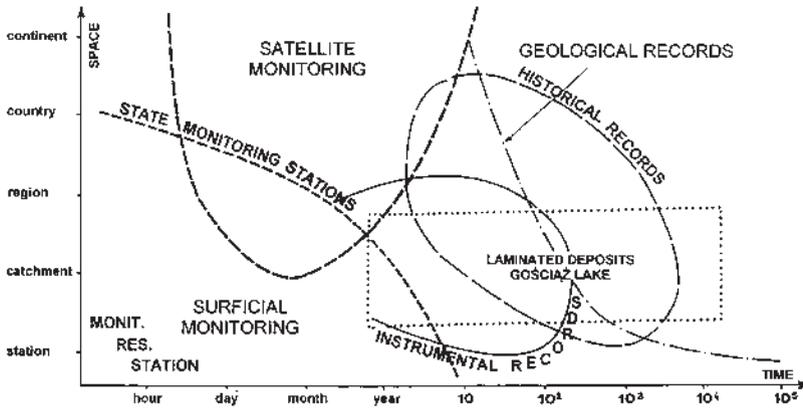


Figure 1. Types of environmental record registered over various spatial and temporal scales enabling better understanding of interrelations between present-day changes and their effects in longer time.

cited examples will therefore be based on our experience. This Department conducted extensive monitoring of hydrological and geomorphic slope and fluvial processes in the Polish Carpathians as well as observations on the effects of extreme events in the other climatic regions, and in parallel on the relief transformation and hydrological changes ongoing during the Holocene over Late Pleistocene at various spatial scales.

In the activities of the INQUA Commissions, especially those on the Holocene and on Global Continental Palaeohydrology (GLOCOPH), this correlation between studies on the past and on the present has been underlined strongly (Starkel 1993, Gregory and Benito 2003), especially when the focus is on the role of extreme events and their increasing frequency over recent decades (Baker et al. 1988, Oldfield and Dearing 2003). Without an understanding of the event scale, we could not understand the rate of human intervention in the natural geosystems effected during recent centuries and millennia (Lang et al. 2000; Dearing 2000).

STUDIES ON PRESENT-DAY PROCESSES

The physical, chemical and biological processes of energy exchange and the circulation of matter, and their spatial and/or temporal effects are registered in the Carpathians by continuous monitoring or by repeated instrumental measurements from a daily up to a multi-annual scale (Gerlach 1996; Froehlich 1982; Kotarba 1992; Gil 1999). These studies help us to better understand the annual or diurnal transfer of energy and matter, and to formulate budgets therefore. Against the background of these it is possible to evaluate the role of extreme events, when the thresholds for various processes like overland flow, slope wash, bed load or landsliding have been crossed. A single extreme could disturb an equilibrium, but usually the system comes back to a previous status during the time of relaxation (Brunsdén 1990). The relaxation again depends on climatic conditions, proceeding much faster in a humid climate. Extreme events may be grouped in clusters, when the time interval between events (heavy rain, strong wind, fire) is

too short for relaxation and the river channel, slope or forest system adjusts to a new equilibrium. Studies in the Carpathians and at the margin of Bhutanese Himalaya have shown that the time distance between events during one cluster does not exceed 2–5 years (Starkel and Sarkar 2002) and may be shorter, of the order of months or days (like in Cherrapunji—cf. Starkel et al. 2002). Clusters of events seem to be the main motor of transformation of geosystems (Starkel 2002).

But there are also climatic regions in which the high frequency of extreme events is their normal feature, in that extremes repeat every year. After the degradation of vegetation cover in particular, such a system is here transformed substantially, such that it will never come back to its outgoing or primary stage (as in the Cherrapunji region, Starkel et al. 2002).

The spatial extents of extremes may vary depending on their character. Local heavy downpours create changes on the local scale. Summer 1996 was such a characteristic period in southern Poland, with many centers of local soil erosion and flooding (Starkel 1998b). The different reactions of various objects depend on local conditions and sequences of events. This is well illustrated in the diversified trends towards the expansion or retreat of individual glaciers monitored in the Tyrolean Alps for more than one century now (Patzelt 1985). Different effects are observed after continuous rains affecting many thousands of km² as in July 1997 in the Carpathians and Sudetes (Starkel and Grela 1998), or in October 1968 in the Darjeeling Himalaya (Starkel and Basu 2000). After the formation of new landslides the relaxation time over slopes fluctuated in the Darjeeling region from several to about 30 years, depending on the size and depth of the landslide.

A single event of global extent has not been recorded in the last decade.

The monitoring of geomorphic, sedimentologic or ecological effects of present-day extreme events may help in the reconstruction of similar events in the past records.

STUDIES ON CHANGES IN THE PAST

Environmental changes in the past are reconstructed on the basis of examination of inherited sediments, forms, soils and biotic remains. By studying the sedimentological sequence we are able to recognize long-term trends and fluctuations. It is of course not easy to differentiate between long-term and short-term variations, or among the latter to distinguish single events and clusters thereof. The alternation of more humid and drier phases during the Holocene has only been recognized thanks to the interdisciplinary research on various sediment facies and the reconstruction of different environmental parameters. Only then can a variety of extremes (Starkel 2002, 2003) be reconstructed. Among them the effects of heavy downpours, continuous rains and long rainy seasons may be recognized. Heavy downpours are reflected in the proluvial and deluvial sediments of small catchments (Niedziałkowska et al. 1977) and in the fresh debris-flows above the upper forest limit (Kotarba 1995). Continuous rains are registered in flood deposits and forms, as well as in landslides simultaneously in larger catchments (Starkel 2002). Finally a rainy season may be reconstructed from lake level rises, a high rate of bog deposition and in the formation of deep rocky landslides (Starkel 2003).

For the recognition of temporal changes the parallel study of both continuous undisturbed sequences and discontinuous ones is needed. The undisturbed sequences are deposited in the very stable conditions of lakes with annually laminated sediments like in lake Gościąg (Ralska-Jasiewiczowa et al. 1998). Thanks to them we obtain a very detailed chronostratigraphy, though extreme events are usually not registered there. For that reason we need to consider the discontinuous sequences of fluvial or slope deposits in which distinct breaks, cuts and fills or a rapid change in grain size reflect the course of extreme events (Starkel 1983, 2002). The discovery in such a number of sedimentary units reflecting single rains or floods (Niedziałkowska et al. 1977; Starkel

et al. 1996) has created the basis for a model of phases composed of events and their clusters (Starkel 2003a, Figure 2). Among the most expressive factors controlling the phases of higher intensity of processes are the phases of reduced solar radiation (Stu-

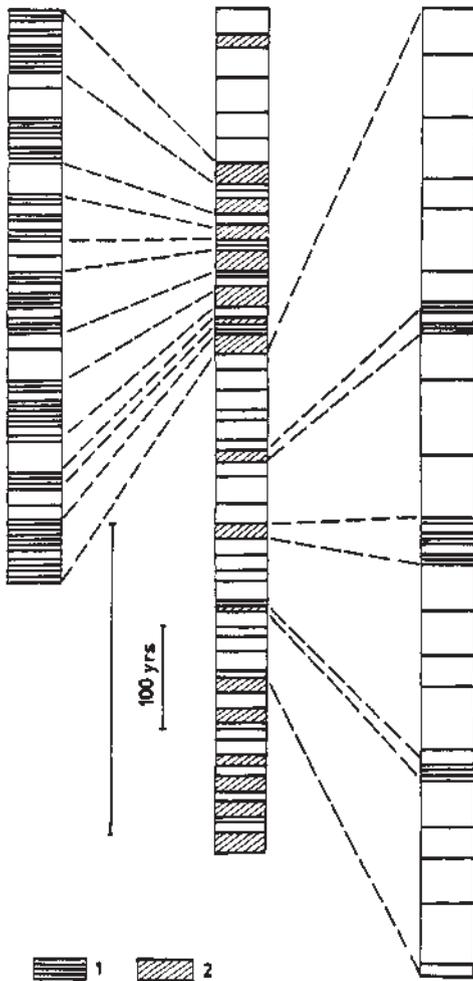


Figure 2. Hierarchic model of system: phase—cluster—event. In the middle alternate phases with varying frequency of extreme events (1) and clusterings (2). On the left wetter phase with frequent clusters. On the right the phase with lower frequency of events.

iver 1995) and high volcanic activity (Bryson and Bryson 1998) that have been recognized (Starkel 2003a, Issar 2003). The increasing role of anthropogenic factors (deforestation, overgrazing and soil cultivation) has caused an acceleration of processes. The most pronounced degradation and deposition is therefore known from the periods during which the more humid climatically-controlled phase coincide with a time of increased human activity (cf. Starkel forthcoming).

Studying the sedimentary sequences it is also possible to recognize the phases of rapid climatic changes. Especially well documented in ice cores and laminated lake sequences is the rapid warming of the order 3–5°C in mean annual temperature noted over several decades at the Younger Dryas-Preboreal transition (Goslar et al. 1995).

OVERLAPPING OF METHODS BY STUDYING CHANGES IN LAST CENTURIES

Of special importance for a better understanding of present-day trends, as well as the mechanism of transformations in the past is the parallel use of various methods in studying changes in the last 2–3 centuries. For this period we have at our disposal not only the instrumental records, but also historical records and great variety of geological records.

Instrumental records are represented mainly by measurements of temperature and precipitation, going back 200 yrs in the case of Poland (Rojecki 1966), as well as water-level fluctuations on main rivers (Starkel 1998a, 2001). Historical-record chronicles, old maps etc. are mainly related to extreme events. The extreme floods in the last millennium have good coverage, especially from the 16th century (Brazdil et al. 1999). But there is also information on droughts, heat-waves, heavy frost, strong winds etc. (Pfister 1992).

Environmental changes during last centuries were also recognized through the use of classical geological methods like the sedimentological, palynological, dendroclimatological techniques and others. Of special importance was the discovery of annually

laminated sediments at the Gościąg Lake near Płock in the Vistula valley in the 1980s (Ralska-Jasiewiczowa et al. 1987). It was possible there to identify changes year after year (Ralska-Jasiewiczowa et al. 1998). Of great value are the other methods of absolute dating starting from radionuclides (^{14}C , ^{210}Pb , ^{137}Cs), dendrochronology and lichenometry. The confrontation of results obtained by various methods makes it possible to distinguish shorter episodes (events, clusters) from phases several centuries long and allows one to try to reconstruct the mechanism behind changes. It was very valuable that this period of the last 2–3 centuries contains the closing part of the Little Ice Age (to 1850 AD), this being the last Holocene phase with a very high frequency of extreme events and decadal-scale changes.

It is due to these complex investigations that the question of accelerated gully formation and a distinct trend for channel transformations from meandering towards braiding have started to be clear (Szumański 1977). In studies of environmental changes in the Tatra Mts during the last two and a half centuries, parallel studies involving geomorphology, lichenometry, old photos of debris flows, dendroclimatology, the dating of lake sediments by ^{210}Pb and ^{137}Cs and instrumental climatic records, historical records on earthquakes, mass-movements and volcanic eruptions have together helped in the reconstruction of the sequence of changes and to delimit the end of the Little Ice Age (Kotarba 1992, 1995).

Studying the last centuries by various methods we are able to evaluate changes in both quantitative and qualitative ways as well as to provide a better recognition of the long-term trends and understanding of the spatial diversity of geosystems.

FINAL REMARKS

Concluding in regard to the reconstruction of environmental changes over time it is clear that we may use two ways of deduction: from processes to effects (forms, sediments, plant communities) or vice versa.

Starting from inherited elements (sediments, forms, soils, plant or animal remains) we recognize at the beginning the characteristic features of geosystems and the trends and rates of the changes thereto. Then follows the recognition of events and their clusters, if available. Various parameters for sediments, forms and biotic remains serve as indicators of physical and bio-chemical processes. The correlation of the various records for reconstruction of climatic, tectonic or antropogenic causes of processes evoking environmental changes is the final stage (cf. Starkel 2003a).

The opposite means of deduction starts from the monitoring of processes combined with a recognition of their creative forces. Then follows observation of effects of events leading to direct changes in various rates. Finally these effects are registered in the sediments with biotic remains and forms (Kotarba 1995).

Parallel investigation of inherited environmental elements and of proceeding changes helps not only in the recognition the whole chain of changes but also to forecast future environmental changes (Gregory 2000; Starkel 2003b). Study of the past explains the course of the long-term changes and the role of various frequencies of extremes in them. Of great importance is the diagnosis of the role of human intervention in the acceleration of circulation of matter and in energy transfer (Gerlach 1976; Gil 1999; Soja 2002; Starkel forthcoming). These studies are also of practical values. The knowledge of trends in the evolution of the Carpathians landscape—the main region of our investigation—enables the forecasting of a gradual decline in the rate of soil erosion due to the retreat of the arable land on the one hand, and of increase in the role of extreme events caused by the global warming on the other.

In contrast, the monitoring of present-day processes helps in quantitative recognition of the energy exchange and circulation of matter as well as in the evaluation of their causes. Repeated measurements help us evaluate the role of single events and their

clusters, which vary in space in relation to local conditions.

One of the most important conclusions arising from these parallel studies on past and present is the following: existing geocosystems are composed of elements of various ages, many of them inherited from the past (Starkel 1999). This means that future environmental changes also, even those provoked by global warming and various kinds of human intervention, will be controlled to a large extent by such elements rooted in the past as geological structure, relief and soils immensely differentiated over space.

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CHANGES IN VEGETATION AND SOILS OF THE EAST EUROPEAN PLAIN TO BE EXPECTED IN THE 21st CENTURY DUE TO THE ANTROPOGENIC CHANGES IN CLIMATE *

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Abstract: The paleogeographic analog method has been applied to estimate future changes in the state of the main components of the environment on the East European Plain at three time intervals within the 21st century (the 2030s, 2050s, and 2080s). Two warm epochs of the past, the Holocene optimum (*c.*5.5 kyr BP) and the Mikulino (Eemian) interglacial optimum (*c.*125 kyr BP) have been chosen as the paleoanalogs. In the first decades of the 21st century the most probable changes involve herbaceous plants and tree regrowth. It will only be by the end of the century that tree-species penetration of new areas and shifts of zonal boundaries may be expected. The predicted increase in potential evaporation may result in a reduction of wetland areas and slower peat formation. In the north of the Plain, soil-forming processes will presumably respond to warming mainly via accelerated humification. Somewhat enhanced leaching would be typical for the subzone of podzolic soils at the end of the century, thus bringing about the initial phase of sod-podzolic soil formation. The area of chestnut soils will show a tendency to decrease as compared with the present day. Some undesirable geomorphological processes and natural hazards are also considered.

Key words: warming of climate, changes in vegetation and soils, the paleogeographic analog method, East European Plain.

INTRODUCTION

When estimating probable changes in the environment to be expected at different time intervals in the 21st century, we mainly used scenarios obtained by numerical modelling (e.g. the Atmosphere and Ocean General Circulation Model—AOGCM—Climate Change... 1996, 2001), and paleogeographic

analogs (Atlas of Palaeoenvironments... 1992; Velichko et al. 1998). According to the general circulation model (GCM) of the atmosphere (Climate Change 1996), mean global temperature will have risen in comparison with the 1980s–1990s by 0.7–0.8°C by the 2030s, by 1.7–1.8°C by the 2050s, and by 2.4–2.5°C by the 2080s (when the carbon dioxide concentration will be twice its present value). The warming value would not be evenly distributed, however. As has already been shown by paleoanalogs (Velichko et al. 1983, 1984) and later—by modelling

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(Climate Change... 1996, 2001), the warming will be most pronounced in Arctic regions of the Northern Hemisphere, and in particular—in its eastern part. Temperatures in the tropical and subtropical regions will presumably show but negligible positive or negative deviations from the modern values. One of the recent publications deals with regional characteristics of predicted climatic changes and environmental response over Russian territory (Regional aspects... 2001).

SCENARIOS OF CLIMATES AS A STARTING POINT FOR ESTIMATES OF LANDSCAPE CHANGES

To assess the expected changes in landscapes we use spatial reconstructions of climatic parameters (temperatures, precipitation, potential evaporation, etc.). The chosen time intervals, however, differ markedly in terms of the reconstructions available. At present, there are numerous scenarios for the case in which CO₂ concentration in the atmosphere is doubled. They take into account both increased carbon dioxide content and the sulfate aerosol effect. Usually, the scenarios encompass temperatures (summer, winter, mean annual) and total annual precipitation (Santer et al. 1996; Climate Change... 1996). Another group of paleoclimatic maps have been obtained by the team at the Laboratory of Evolutionary Geography (Institute of Geography, Russian Academy of Sciences) using methods involving climagrams, areagrams, as well as the information-statistical technique, for two time intervals of the past—the optimums of the Holocene and of the last (Mikulino, Eemian) interglacial, 5.5 and c.125 kyr BP respectively. These intervals may be used with a fair degree of confidence as analogs in estimating changes in the soil and vegetation during the 21st century, especially as analyses of gas composition in ice cores have revealed an increased CO₂ concentration in the atmosphere at the interglacial optimums (Kotlyakov and Lorius 1989).

Several spatial reconstructions of climatic parameters have been obtained for each

of the time intervals, including as regards temperatures for the warmest and coldest months, mean annual temperatures, seasonal and total annual precipitation, potential evaporation and duration of the frost-free period (Velichko et al. 1982, 1983, 1984, 1998; Atlas of Palaeoclimates... 1992). By calculating mean values of temperature within every 10° latitudinal belt of the Earth's surface, it was estimated that the mean global temperature during the first optimum was 0.7–1°C above that of today and that during the second 1.7–1.8°C higher (Atlas of Palaeoclimates 1992). It may be easily seen that those deviations in global temperature are close to those expected in the 2030s and 2050s. When comparing spatial reconstructions of mean annual temperatures over the territory considered on the basis of paleodata (the case of global temperatures 1.8°C above those of today) and those obtained via general circulation model calculations for a case of doubled of CO₂ in the atmosphere, the general pattern seems to be similar, though there are also some differences in the details. Thus, the GCM suggests a rise in mean annual temperature by 4°C in the northernmost regions of the East European Plain (north of c.65°N) only, while in paleoreconstructions the +4°C deviation goes as far south as 52°N. For the greater part of the plain and the Caucasus paleotemperatures calculated from the GCM are 2°C above the present ones, with only the area between the Black and Caspian seas showing temperatures close to those of today. According to the paleoreconstructions, an increase in temperatures of 2°C is seen to about 50°N, a belt of negligible deviations is traced to northern Black Sea coastal regions and the Caspian Lowland (in common with GCM), and slightly negative deviations from modern temperatures are found in the North Caucasian forelands and in mountains. The model developed by Manabe (1997) presents an intermediate variant, with mean annual temperature more than 3°C above the present day values over the greater part of the considered area.

When comparing the distribution of positive deviations of annual precipitation from

the modern values calculated using the Jones model (Kattenberg et al. 1996), for a case of a doubled concentration of CO₂, with the distribution obtained from paleodata, there is a certain similarity in the pattern to be observed. In both cases, for the Mikulino (Eemian) interglacial optimum, positive deviations in excess of 100 mm are found in the north of the East European Plain, and ones of less than 100 mm in the middle part of the Plain. There is a diversity, however, for the southern regions. The values of positive deviations obtained from paleodata are as great as 200 mm, while the calculations based on GCM yield no more than 100 mm.

Having no GCM data on the precipitation changes for a warming of smaller range, there remain only paleoanalogs in that case. When estimating possible changes in the state of biota, a precipitation to potential evaporation relationship was applied, along with data on seasonal and mean annual temperatures and total precipitation.

This paper presents results of studies based on spatial climatic reconstructions inferred from proxy data. This approach seems to be appropriate, as the paleoclimatic reconstructions have been compiled in complex with spatial reconstruction of individual constituents of paleo-environments for the same time intervals (Velichko 1984, 1991, 1992; Velichko et al. 1995). Though the reconstructions of paleolandscape components do not correspond to the short-period changes expected during the coming decades, they may be used to assess the prospects and trends in the environmental evolution. Quantitative estimates of climatic fluctuations and the rate of the landscape response (mostly that of plant communities and soils) have been discussed elsewhere (Velichko et al. 1991, 1995; Velichko and Morozova 1996).

RESULTS

Considered below are probable changes to be expected in the state of environmental components as a result of the human-induced warming over three time intervals within the 21st

century. The intervals are tentatively chosen as corresponding to global warming (compared to the 2nd half of the 20th century) by 0.7–1°C (the first 20–30 years), 1.7–1.8°C (middle of the century, the 2050s), and by 2–2.5°C (the last decades). The given estimates have been obtained mainly by the team of the Laboratory of Evolutionary Geography (Institute of Geography, Russian Academy of Sciences), with a contribution from L. O. Karpachevsky (Soil Science Faculty, Moscow State University).

POTENTIAL VEGETATION

When analyzing changes in potential vegetation resulting from anthropogenic warming, one of the most important factors to be considered is the rate of migration of forest-forming arboreal species. Calculations based on ¹⁴C-dated plant remains in Western Europe (Huntley and Birks 1983) and in European Russia showed the dispersal rate in the first half of the Holocene was 200–300 m/year for a majority of trees and as much as 500–1000 m/year for birch and aspen. Therefore, changes in the composition of plant communities related to plant dispersal outside their present-day ranges would inevitably lag behind climatic changes (Velichko et al. 1991). Table 1 and Figures 1 and 2 summarize expected changes in potential vegetation of the East European Plain during the three intervals mentioned above.

In the first decades of the 21st century (the 2020s–2030s, DT=0.7–1°C), one can hardly expect a noticeable shift in zonal boundaries. Most probably, the changes will be restricted to the internal structure of communities (composition of understory, young trees, bushes and herbs). In the tundra zone, an increase in precipitation, higher temperatures and a resulting increase in the active (seasonally thawed) layer thickness will encourage an abundance of hygrophilic, relatively thermophilic herbs and grasses (of local tundra species); dwarf shrubs will also gain in importance. Those changes will proceed, along with an increase in intensity of solifluction and thermokarst processes, which may locally result in disturbance of vegetation cover.

In the forest-tundra, tree species will gain in importance (birch in particular). In the boreal forests (subzone of dark coniferous taiga), birch and aspen will be more abundant among young trees, as the more cold-tolerant species become suppressed in primary plant communities. In the subzone of coniferous-broadleaf forests climatic conditions will be more favorable for some broadleaf species (such as *Quercus robur*),

and their proportion in the young growth will be more conspicuous. Birch and aspen will appear in primary phytocoenoses. Closer to the southern boundary of the zone, the role of spruce will diminish. In the broadleaf forest zone there will be enhanced regeneration (regrowth) of broadleaf species (oak and lime, with hornbeam in the west). This process will possibly result in an increase of those species, importance in the plant com-

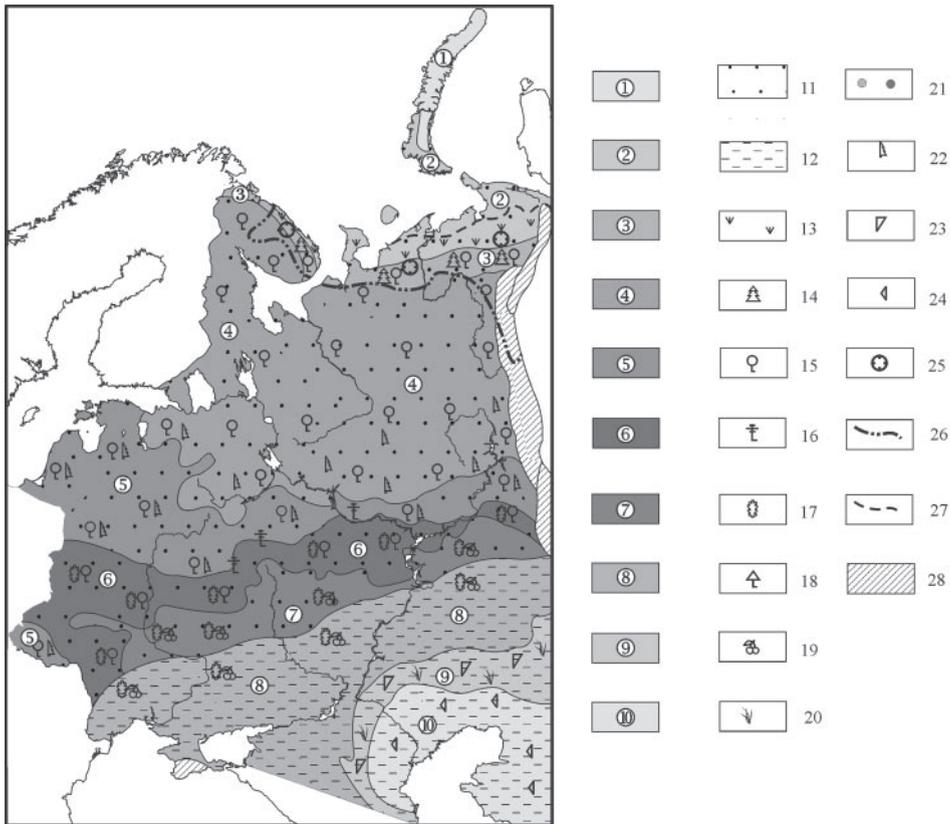


Figure 1. Expected changes in vegetation in 2030s.

Vegetation zones: 1—arctic desert, 2—tundra, 3—forest tundra, 4—coniferous forest, 5—coniferous-broadleaved forest, 6—broad-leaved forest, 7—forest steppe, 8—steppe, 9—semi-desert, 10—desert; increasing role in the plant communities of: 11—relatively thermophilous species, 12—relatively mesophilous species, 13—tundra shrubs, 14—spruce, 15—birch, 16—pine, 17—oak and other broad-leaved trees, 18—hornbeam, 19—steppe shrubs, 20—grasses; 21—penetration of vegetation elements from the adjacent zones; decreasing role in the plant communities of: 22—spruce, 23—sagebrush, 24—desert plants; 25—permafrost boundaries: 26—modern, 27—expected; 28—mountain areas.

Table 1. Expected processes of plant community restructuring due to anthropogenic warming

Modern vegetation	Processes to be expected in the 2020s–2030s	Processes to be expected in the 2050s.	Processes to be expected at the end of the 21st century
Tundra	Bushes and thermophilous herbs grow in abundance	Shrub tundra expansion at the expense of moss tundra	Tree species dispersal, northward shift of tree limit
Birch and spruce forest-tundra	Trees grow in abundance due to local availability of seeds	Area of forest and parkland communities increases	Density of forest communities increases, thermophilous forest elements introduced in south
Dark coniferous European taiga	Primary coenoses show increase in abundance of birch and aspen	Proportion of thermophilous elements increases	Broadleaf immigrants in south
Coniferous-broadleaf forests	Increase in abundance of thermophilous herbs, birch and aspen in primary coenoses; increase in abundance of oak and other broadleaf species in understory. Spruce may become less abundant near the southern limit of its range	Increase in abundance of broadleaf species. Spruce is gradually reduced up to its complete disappearance in southern part of area.	Gradual reduce in abundance of boreal elements, dominant are herb, bush and tree species typical for broadleaf forests
Broadleaf forests	Increase in abundance of thermophilous species (herbs, young trees and bushes)	Processes initiated in the 2030s continue	Dispersal of hornbeam, beech and other members of their communities east of their present ranges
Broadleaf forest-steppe	Increase in the number of trees owing to locally available seeds, trees' expansion into steppe areas	Processes initiated in the 2030s continue	Immigration of hornbeam and members of its community into central and eastern regions of forest-steppe
Steppe	Tree dispersal from river valleys and planted forest stands, growing abundance of mesophilous herbs and grasses	Processes initiated in the 2030s continue	Immigration of thermophilous plants from west
Semidesert	Increase in number of grass and other mesophilous components due to locally available seeds. <i>Artemisia</i> becomes less important in coenoses	Processes initiated in the 2030s continue. Mesophilous steppe elements begin to penetrate in north	Immigration of steppe species
Desert	Increase in number of grass and other mesophilous components due to locally available seeds. Edificators (environment forming plants) of desert communities are reduced in importance	Processes initiated in the 2030s continue	Mesophilous plant communities formed with species of local flora; immigrant species may participate in north

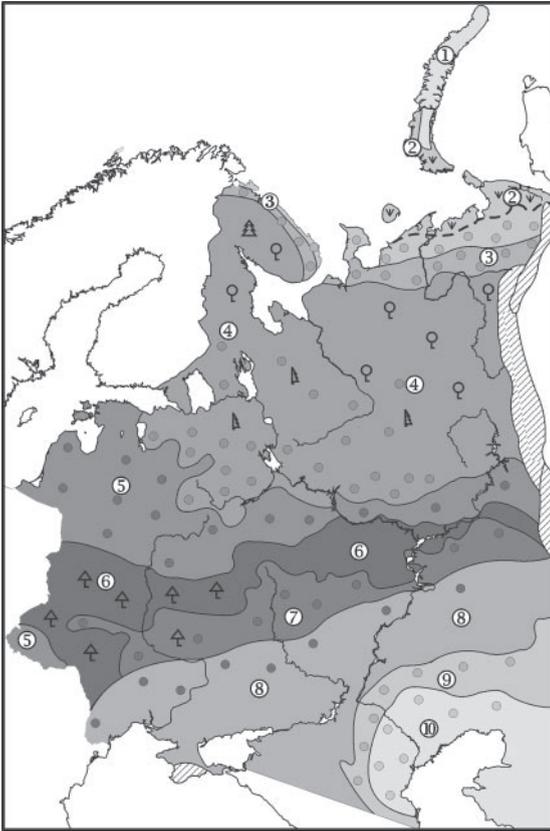


Figure 2. Expected changes in vegetation in 2080s.
For explanations see Figure 1.

munities). In the central part of the Plain (the Upper Volga basin and Central Russian Upland), annual precipitation will be somewhat lower. That would lead to pine becoming more important, on sands in particular, while in the forest-steppe communities one might expect tree species to be slightly depressed. In the southern part of the Plain, within the steppe and semidesert zone, mesophilic components will become more important (because of locally available seeds). Some decrease in the abundance of *Artemisia* may be expected in semidesert.

In the middle of the century (the 2050s, $DT=1.7-1.8^{\circ}C$) both summer and winter temperatures will have risen to a degree

where potential evaporation will be of more than 100 mm/year above the recent values all over the East European Plain, and north of $63-65^{\circ}N$ in particular, in spite of an increase in precipitation (Velichko et al. 1982). Consequently, the amount of surface moisture will be reduced, even in the tundra, with the result that shrub tundra will expand at the expense of typical moss tundra. Trees will disperse from the forest-tundra boundary northwards, along river valleys and occasionally onto flat interflues. Taking into consideration the rate of tree species migration, however, the total northward shift of the tree limit will hardly exceed 20–30 km. In the boreal subzone of the forest zone thermophilous plants (mostly herbs and grass) will disperse northward. Broadleaf species will gain in importance within the coniferous-broadleaf subzone. Because of the rise in winter temperatures, the growth of spruce will be slowed. Birch and aspen will gain in importance in the primary forest communities. In the broadleaf subzone, some western species, such as hornbeam, beech and other members of the hornbeam community, will migrate eastward by a few tens of kilometers; in the forest-steppe, tree communities of broadleaf species, birch and aspen will increase in area. Trees will also penetrate into steppes along river valleys. Qualitative changes in biomes are to be expected in steppes and more so—in semideserts, where summer temperatures will be similar to the modern ones while rainfall amount will rise by 50% (Velichko et al. 1982). That will produce favorable conditions for mesophilous herbaceous plants. In the Caspian region wormwood and other undershrubs—edificators of semidesert plant communities—will be replaced by grass and mesophilous herbs.

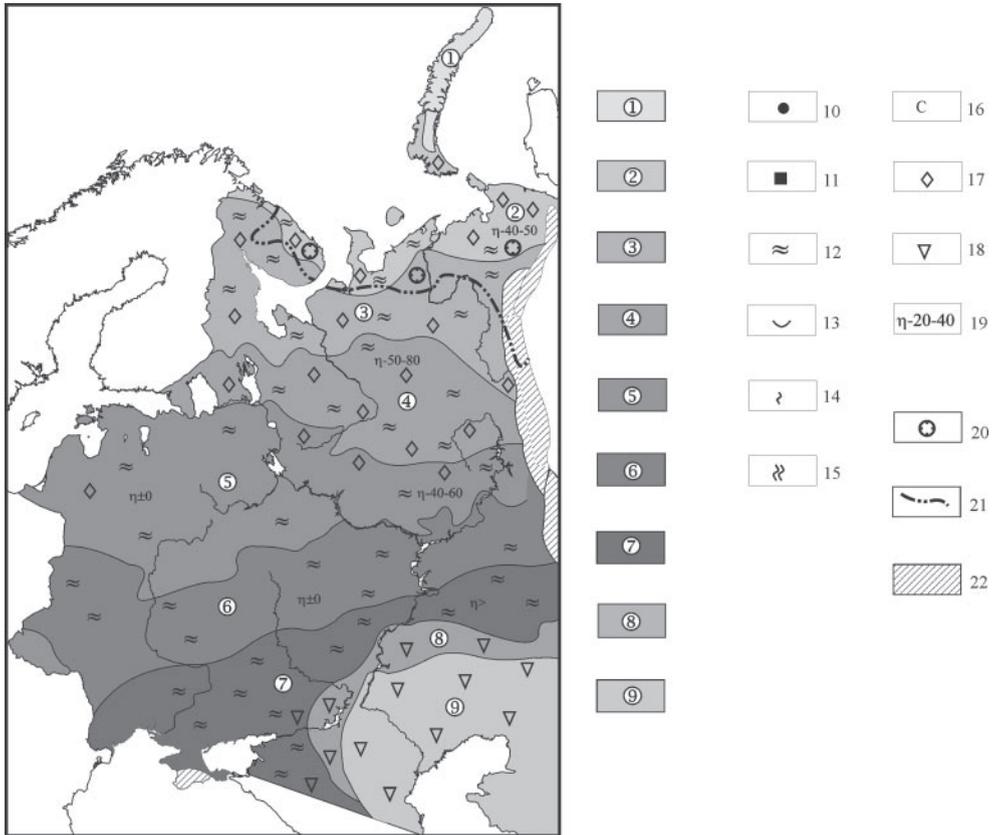


Figure 3. Expected changes in soils in 2030s.

Zonal types of soils: 1—arctic, 2—tundra, 3—gley-podzolic, 4—podzolic, 5—sod-podzolic, 6—grey forest soils and leached chernozems, 7—ordinary and southern chernozems, 8—chestnut soils, 9—light chestnut and brown semi-desert soils; activation of pedogenic processes: 10—humification, 11—humus accumulation, 12—biological activity, 13—podzolization, 14—lessivage, 15—lessivage and surface gleization, 16—accumulation of micellar carbonates; 17—reducing of gleization; 18—desalinization; 19—deviation of soil water reserves from the modern values (mm); 20—thermokarst development; 21—modern boundary of permafrost; 22—mountain soils.

The last decades of the 21st century ($DT=2-2.5^{\circ}C$). When considering the state of vegetation in so distant a future as the end of the century, the following points should be taken into account:

- GCM data on heat and moisture supply in the case of a doubled carbon dioxide concentration do not differ fundamentally from those reconstructed from proxy paleo-data for the Mikulino Interglacial optimum;

- the main trends in vegetation cover evolution to the end of the century may be found by proceeding from the Mikulino vegetation reconstruction and using data on characteristic time for individual components of the landscape (that is, the time of change and attainment of equilibrium with an established climatic regime).

One can confidently suppose that, though the northern forest limit will shift

Table 2. Expected changes in soil-forming processes due to anthropogenic warming

Modern soil types	Changes in the first decades of the 21st century	Changes in the second half of the 21st century
Tundra gley soils (gelic gleysols)	Reduced summer water storage. Accelerated humification	Initial stages of illuviation
Podzols (middle taiga) (podzoluvisols)	Reduced summer water storage. Intensified processes of litter decay	Decelerated gleying processes. Intensified processes of illuviation
Ordinary (haplic/calcic) and southern chernozems	Increase in summer water storage	Changes in newly-formed carbonates
Chestnut soils of dry steppe (kastanozems)	Increase in summer water storage	Reduced alkalinity

north by 30–50 km at most, the climate will be suitable for the dispersal of tree species as far as the Arctic Ocean coast; therefore, individual trees may appear locally all over the territory. Essential changes are expected in the southern part of the dark coniferous taiga forests—under conditions of winter temperatures as high as 0... –2°C spruce may disappear from the biome, being replaced by birch and locally by pine; broadleaf species are likely to penetrate into the zone. The broadleaf forest subzone will expand not only northwards, but to the east and south, at least onto the modern forest-steppe area. The latter would shift southwards, by 50–70 km at the end of the century. In the steppe zone there will be favorable conditions for arboreal species penetration along valleys. In the desert and semidesert the vegetation would acquire more noticeable mesic characteristic (locally also due to immigrants).

WETLANDS

Northern and northwestern parts of the East European Plain have wetlands covering a considerable proportion of their area, up to 30% in the drainage basins of the Pechora and Severnaya Dvina, the upper reaches of the Dnieper, and in Karelia (Markov et al. 1998). As the potential evaporation in the region will presumably be 100 mm above today's level, a progressive reduction of the

wetland area can be expected, as well as somewhat slower peat formation.

SOILS

Soils on the whole show a longer characteristic time for change under conditions of a changing climate. Besides, the soil profile itself presents a combination of heterogenous and heterochronous characteristics, each with its own characteristic time of transformation. Three main groups of processes may be distinguished by different time of transformation:

- rapidly changing processes (time of response is a year to several years)—migration of easily soluble compounds, biological activities;
- processes with a response time of several decades—changes in acidity, alkalinity, salinity and gleying;
- processes with a response time of a hundred years and more—humus content changes, migration of carbonates, iron and aluminium oxides, clay particles.

Proceeding from the above, one can confidently expect intensified humification processes within coarse humus and peat horizons in the zone of tundra gley soils in the first quarter of the 21st century; in its second half humification will continue, together with an initial stage of podzolization (Table 2, Figures 3 and 4).

In the subzone of podzolic soils (podzoluvisols) the first decades will see an intensified

process of litter decomposition. Towards the middle of the century, gleying processes are expected to be depressed against the background of enhanced illuviation of fine particles (<0.002 mm). By the end of the century, there will be an initial phase of sod-podzolic soil formation, along with accelerated lessivage processes. (Velichko and Morozova 1996; Morozova et al. 1998).

In the zone of gray forest soils (gryezems) and in the north of the chernozemic zone (in the central part of the Plain), a decrease in annual precipitation may result in easily soluble salts being drawn towards the surface. Over the main part of the chernozem soil zone the new formation of carbonates will change, micellar carbonate chernozems will gain in importance in the south. Towards the end of the century, processes of meadow chernozem formation will intensify.

Within the present area of kastanozems (the south-east of the Plain), alkalinity (solonetzicity) will decrease as in early as the first decades; the area of chestnut soils will tend to reduce towards the last decades of the 21st century.

WATER STORED IN SOILS

Changes in the amount of water stored in the upper meter of soils have been studied by Karpachevsky, Velichko and Morozova (1995). It appears that the trends for changes could be opposite to each other in different regions. It follows from calculated values, that summer water storage in podzolic soils formed on a loamy sediment will be reduced by 500–100 mm; the same reduction is to be expected in the tundra zone during the second half of the century. In the east of the gray forest soil (gryezems) subzone, and in the central region of the Plain in particular, there will be a pronounced trend towards decreased soil moisture (by 100 mm and more). No essential changes are predicted

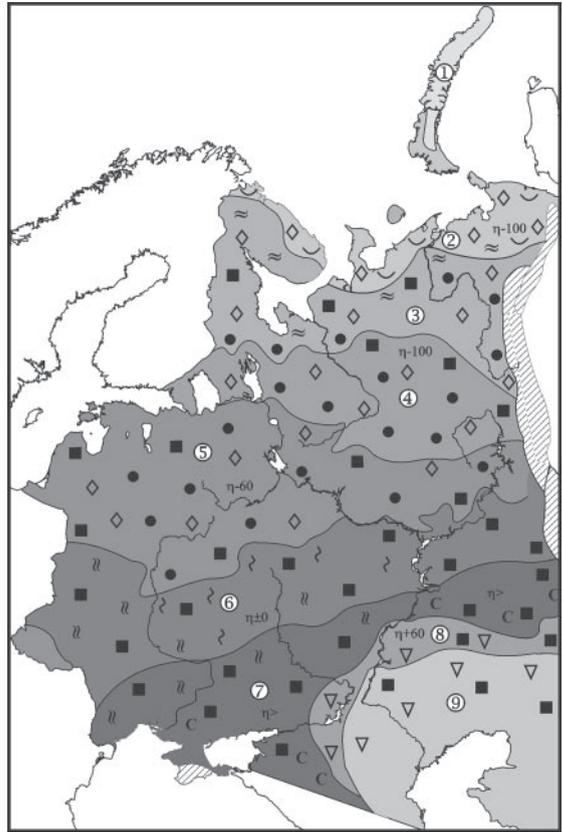


Figure 4. Expected changes in soils in 2080s.

For explanations see Figure 3.

in the main part of the chernozem zone. Within the southern (calcic) chernozem subzone and that of kastanozems (mostly in the east) an increase in stored moisture of 60 to 80 mm is to be expected.

GEOMORPHIC PROCESSES AND NATURAL HAZARDS

Along with biota transformations, the coming changes in climate would affect geomorphic processes. In the first decades the decay of permafrost would result in solifluction processes, and ice wedge thawing would enhance linear erosion and the development of gullies; on the whole, the land surface will be less stable. The named processes, however, would lose some of their intensity towards the

middle and in the second half of the century, when moisture content in the surface layer of soil is reduced. As for the forest zone, the modern relief-forming processes are unlikely to change noticeably. A number of negative effects are possible in the central regions of the plain due to a decrease in summer rainfall. An appearance of desiccation fissures may lead to intensified erosion by meltwater in spring and, in case of heavy rains, in summer; the accelerated erosion may result locally in badland topography. Other effects are a higher frequency of dust storms and an increase of solid runoff. Those processes may be stimulated by large topographic features (the Central Russian Upland).

The negative phenomena would gradually lose their intensity in the second half of the century. In steppes an accelerated erosion is most probable in the first decades, until an increase in plant cover density has compensated for higher rainfall. Later on, the erosion will decelerate due to denser swards (unless the land is ploughed).

Special attention should be paid to mountain ecosystems, such as the Carpathians and Caucasus. Natural hazards may intensify there due to an increase in annual precipitation of 300 mm (Velichko et al. 1982). More abundant snowfalls may result in more frequent avalanches, while heavier summer rainfall poses threats of mudflows and landslides, in particular near settlements and on roads. Similar hazards are to be expected in the mountains of Central Asia.

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CHANGES IN THE MIDDLE COURSE OF THE RIVER VISTULA IN HISTORICAL TIMES

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Abstract: An attempt is made to reconstruct the sequence of change in a part of the Middle Vistula valley between the 11th and late 20th centuries, using historical methods. The most detailed analysis was possible for the changes of the last 250 years. It was possible to document the time of the onset of the change in the character of the river from dominantly meandering to one that was characterised by braiding, suggesting the anthropogenic influences that have modified the natural processes (for example: deforestation, changes in rural management, development of flood embankments).

Key words: Vistula river valley, historical analyses, bed river channel changes.

INTRODUCTION

The work described here aims to reconstruct the process whereby the River Vistula changed from a meandering to a braided channel, considering how the changes involved related to changes in the natural environment and the influence of human activity. The work was inspired by the observation that the shape of the river corridor on old maps did not accord with the widely-held view that the change in the nature of the corridor arose in Renaissance times as a result of deforestation in the Carpathians and of the river valley, as well as from agricultural management of the drainage basin. The problem of environmental changes is often being dealt with in many European countries. It is usually based on rich archives and cadastral maps as in The Netherlands, Great Britain, or the Czech Republic. In Poland, such research has rather a detective character due to a lack of detailed maps and

documents which were damaged during the Second World War.

The present work forms the third and final part of a larger whole, in which each part has employed the same methodology, working on analogous source materials. Publications already issued have been concerned with the Józefów–Kazimierz Dolny section (Kalicki and Plit 2003) and that of Wargocin–Magnuszew (Plit 2002, 2004). The article has made use of elements from: Plit J., 2004, Kalicki and Plit 2003.

Reconstruction of changes in the Vistula channel and their association (of this process) with the changes in the settlement system and land use in the valley constitute the primary objectives of the present study. The analysis relates to the period from the 10th to the 21st centuries inclusive. Through to the 18th century, the main sources are archival documents and studies by historians, while the subsequent period depends primarily on cartographic materials. The research

has focused on a 55 km section of the Vistula valley between Kazimierz and Wargocin.

Although this section of the Vistula valley has featured in the work of many others, such that the stages of its development have been reconstructed,¹ the level of geomorphological recognition of the section from Puławy to the confluence with the Pilica is limited (Starkel 2001). The geomorphological basis for this present work is thus confined to a geological map and associated commentary (Żarski 1991,1996), as well as to studies by Pożaryski, Maruszczak and Lindner (1994) and Maruszczak (1997).

The middle course of the Vistula river valley, where the river crosses the gap in the Małopolska Uplands and flows into the Mazovian Plain, is a favoured area for the study of changes in cultural landscapes. Over the centuries, this territory was subject to dramatic historic events. Numerous wars and uprisings ravaged the area, destroying villages and towns. During the entire Polish 'golden age' of the 15th and 16th centuries the region flourished economically (Gierszewski 1982; Kurzyp 1989; Pacuski 1993; Wojciechowski 1966). However, since the end of the 18th century, when the Vistula ceased to play a more major role as a transport route, the area has been in recession (Gierszewski 1982; Kurzyp 1989). The frequent changes of the Vistula river channel, floods, and the eroding activity of the river, have ensured that this area, inhabited for 1000 years, is almost entirely free of architectural monuments. Numerous localities had to be rebuilt several times or moved to other, safer, places. Anthropogenic transformation, resulting from centuries of superimposed human impacts, has affected this segment of the Vistula river where there are no major water engineering works so that the river remains unregulated. Indeed, it was only embanked at the end of the 19th century.

The historical analysis presented here was conducted using the retrospective

method, starting from contemporary times and tracing back in time. The results obtained were verified through comparison with detailed geological, geomorphological and potential-vegetation maps.

THE METHOD OF HISTORICAL ANALYSIS AND THE CARTOGRAPHIC SOURCES

The changes in the Vistula river channel over recent centuries were traced by collecting historical data (referring to the river and its valley), while for the last 250 years, use was made of cartographic sources. Ten map series were obtained, encompassing the entire area or fragments of it. The scales to all maps were unified photographically, and they were all standardized under a unified co-ordinate system and identical projection. The basis for this work was assumed to be the Military Topographical Map at 1:100 000, which was issued in 1999.

Use of the oldest maps (from 1759, 1772, 1786, 1788–1791 and 1797) is complicated by significant location errors resulting from a lack of mathematical and geodesic foundations. These maps were based upon the few localities for which astronomical measurements of latitude and longitude existed. Initially, they were elaborated without the use of precise instruments (a lack of precise chronometers causing errors in longitude, for example). In the maps elaborated later, much of the imprecision was brought about by the insufficient density of the triangulation grid, or by ignorance as to the magnitude of magnetic deviation. Until as late as the middle of the 19th century the two sides of the river were charted separately.

In order to unify the source materials it was necessary to re-interpret them. This entailed identification of the common points on both old and contemporary maps. However, many of the characteristic points on old maps do not exist nowadays, and this is particularly the case for the river valley. Consequently, the older the document, the smaller the number of points in common with the present, giving a lower precision

¹ As in Falkowski 1967, 1982, 1996; Kalicki and Pożaryski 1996; Pożaryski, Maruszczak and Lindner 1993, 1994, 1995; Maruszczak 1997, and Pożaryski 1953, 1955, 1994.

and level of detail for the processed map. For the maps elaborated on the basis of a modest triangulation grid, the primary reference points for re-interpretation were constituted by the spot heights. Every effort was made to verify the cartographic material gathered and to complement it with information from other historical documents. Analysis was first carried out from contemporary maps, with a progressive movement backward in time towards the oldest maps (i.e. in the direction opposite to the description provided in the present paper).

The following maps were used of in the cartographic analysis:

1. Mapa Starostwa Stężycznego from 1759.
2. Rizzi-Zannoni's *Carte de la Pologne divisée par provinces et palatinats et subdivisée par districts* of 1772, printed on the scale of 1:692 000. This map formed the background for analysis.
3. F. Czaykowski's *Województwo sandomierskie na powiaty i parafie podzielone r. MDCCLXXXVI (The province of Sandomierz divided into counties and parishes, year MDCCLXXXVI, in Polish)*, published in 1786, but charted earlier, on the scale of 1:185 000.
4. Maps of the atlas of the Crown Provinces of the Polish Commonwealth by Karol de Perthees, 'elaborated in the last years of peace', published on the scale of 1: 225 000. Use was made of *Mappa szczegulna wojewodztwa sandomierskiego z 1788–1791 (A Detailed map of the province of Sandomierz of 1788–1791)* and of *Mappa szczegulna wojewodztwa lubelskiego z 1786 (A Detailed map of the province of Lublin of 1786)*.
5. *Karte eines Theis von Neu oder West Gallicien Welcher die Woywodshafthen Sendomier und Krakau enthalt nebst einem Theil von Alt Gallicien in XVII Blatt*, G. D.Reymann Berlin 1797 (published at the scale of 1:180 000).
6. *Carte von West-Gallizien*, elaborated on the basis of a sparse and not too precise triangulation grid under the supervision of Colonel of the Austrian army, Mayer von Heldensfeld, in the years 1797–1803, on the scale 1:28 800. After generalization, the map was published in Vienna in 1808 at 1:172 800. The mathematical foundations of the map neglect the curvature of the Earth, so that errors appear in the meridional orientation of the map sheets. This map contains detailed information on the location of islands, abandoned loops, degree of change of the valley, etc. These materials were used by Sawicki (1928), who also copied the hand-drawn maps from the Viennese archives, and presented in his work the examples of changes in the Vistula river channel during the 19th century.
7. The Map of the Head Quartermaster's Department of the Polish Army was much more precise and contained more details. The basis for the grid calculation was constituted by the Bessel ellipsoid. Twisting of many fragments of the map is apparent, resulting from a lack of knowledge of magnetic declination. The images of the southern and south-eastern parts of the so-called Congress Kingdom originate from 1832. Table charting was carried out at the scale 1:42 000, and the map was engraved on the scale of 1:126,000.
8. *Novaia topograficheskaia karta zapadnoi Rosi (New topographic map of western Russia, in Russian)*, published at 1:84 000 at the turn of the 20th century. The cartographic projection of the charting was the polyhedral Muffling projection. The basis for the instrumental charting was constituted by the triangulation grid. Field charting was carried out on the scale of 1:21,000. On the basis of this map, the Germans published in the years 1914–15 the *Karte des westlichen Russland* at 1:100 000, which was used in the present study.
9. The battlefield map at the scale of 1:100 000, elaborated by the Military Geographical Institute. The reference basis taken was the polyhedral Muffling projection and the Bessel ellipsoid. This battlefield map is very detailed and precise, with an extensive description. The sheets of interest to our study were developed in 1937.
10. The Military Topographical Map of 1:100 000, published in 1999 by the Topographical Service of the Polish Army, and elaborated by the State Geodesic-Cartographic Enterprise. The universal transversal Mercator projection and the ellipsoid, WGS-84, were assumed.

Initially, the reliability of the reconstructed course of the Vistula river was checked through comparison with detailed relief, geological or geomorphological maps. Nevertheless, the ultimate verification of the results of historical analysis has to be carried out in the field, using geological and geomorphological methods.

DESCRIPTION OF THE CONTEMPORARY NATURAL ENVIRONMENT

The study area extending between the two towns of Kazimierz Dolny and Puławy, a distance of about 15 km, is located within the Vistula Gap through the Małopolska Upland. The valley narrows to 1.2 km, dissecting the resistant layers of the uppermost Maastrichtian near Kazimierz Dolny. The next part downstream is a 40 km course of the Vistula where the river flows on the Mazovian Plain, within which it is unconfined. This section of the valley is 12–16 km wide and located in the old glacial uplands. The fragments of Pleistocene terraces, within which there are boggy depressions filled with peat, appear on both sides of the valley. These terraces, built mainly of sands and gravels and composed of dunes in some places, slope down towards the river, frequently with distinct erosion edges 2 to 7 metres in height. The Holocene flood plains vary from some meters (near Dęblin and Puławy) to 9 km (S of Sieciechów) in width, and are mainly built of fertile fen sediments (Figure 1). Numerous sequences of oxbow lakes of various ages can be observed within the entire valley, but especially on the Holocene flood plains (see the Detailed Geological Map of Poland 1:50,000: Koźienice, Dęblin and Puławy sheet). The contemporary channel of the Vistula is not located centrally in the Holocene valley, but sinuously cuts into the Pleistocene terraces alternately on each side. The river itself has a width of between 500 and 1500 m (at medium discharges), and the channel gradients fluctuate between 0.212 and 0.295‰ (Maruszczak 1997). Along this aggradation segment of the river

the Vistula deposits significant amounts of sand and silt fractions in the channel. Floods usually extend over the lowest, Holocene part of the valley, but every few to a dozen years are sufficient to flood larger areas. The largest catastrophic floods were noted in the 12th, 15th and 16th centuries, as well as in the second half of the 18th and at the end of the 19th centuries (Wąsowiczówna 1957; Kurzyp 1989; Pacuski 1993). The contemporary channel of the Vistula is embanked on both sides, while sequences of older flood-protection structures are preserved along some stretches.

CHANGES IN THE VISTULA CHANNEL

‘In the earliest Medieval times (6th–11th centuries), the Vistula river between Puławy and Koźienice was represented by a well-developed meandering channel... indicative of a relatively dry climate in which the river did not flooded very often... a Holocene flood plain which contained fertile and easy-to-cultivate alluvial soil and variety of terrestrial and water habitats’ (Maruszczak 1997).

The relatively scarce written sources can be used to determine the approximate course of the channel in the Middle Ages. Thus, in the 10th–12th centuries, the river section between Kazimierz and Kochów² flowed to the south of the current channel, when the fortified town of Sieciechów was situated on the right bank. The course of the channel between Gołab and Brzeźce was reconstructed by Maruszczak (1997). As a result of these investigations it was possible to sketch out a geomorphological map (Figure 1). Downstream of Gołab, the Vistula flowed near Gniewosów, Oleksów, Opactwo and Sieciechów, along the left hand bank. It was a sinuous river. The former bed of the river left a complicated system

² From the Middle Ages up to the present day there has been a crossing of the Vistula between Świerże and Kochów. Świerże formerly had a defensive settlement. Places many times destroyed by the Vistula were rebuilt elsewhere. Two villages were located to the NW, about 10 km from Koźienice.

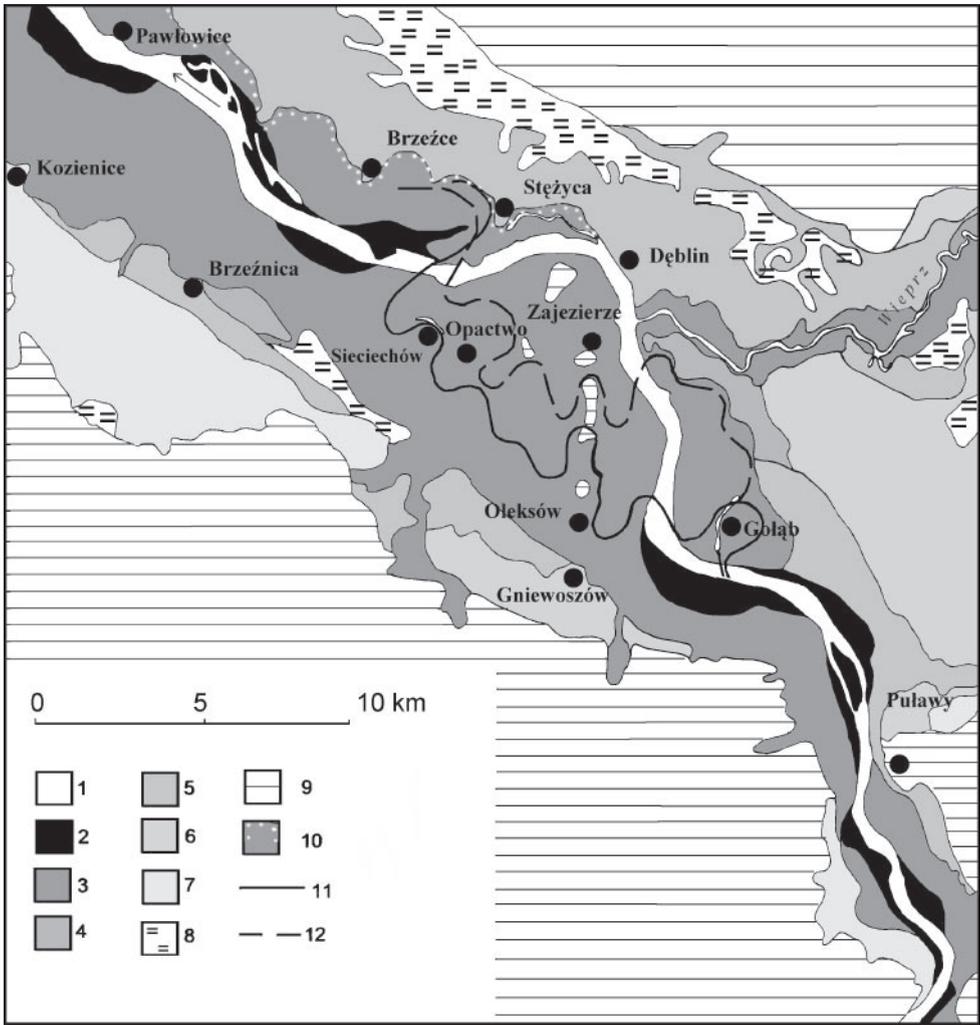


Figure 1. Simplified geomorphological map of part of the Vistula river valley
(from the Detailed Geological Map of Poland 1:50 000).

- 1—River channel, 2—Holocene flood plain, 3—Holocene higher flood plain, 4—Pleistocene lowest terrace, 5—Pleistocene low terrace, 6—Pleistocene middle terrace, 7—Pleistocene high terrace, 8—Peat bog, 9—Plateau, 10—River bank intensive eroded in historical time, 11—River channel in 10th and 11th centuries (reconstructed by H. Maruszczak), 12—River channel in 15th century (reconstructed by H. Maruszczak).

of overgrown oxbow lakes and other lakes that were produced in later years. However, the course of the channel downstream from Sieciechów is in need of correction, since historians like Gacki (1872), Wąsowiczówna

(1957) or Kurzyp (1989) have claimed that:

- The oldest written documents, dating from the 11th and 12th centuries (like the Gallus Anonymus chronicle) have the fortified castle in Sieciechów supervising the

crossing of the Vistula and Wieprz (at that time Sieciechów was situated on a Vistula hillock on the right bank of the river).³

• It was rather later (in the 13th century), that the ducal defensive settlement of Stężyca was erected, with a view to the crossing of the Vistula being controlled. The stronghold was located in the valley floor about 1 km west of today's town (and it was in this very place that H. Maruszczak delimited the Vistula channel of the 10th to 15th centuries).

The meandering Vistula flowed south of Sieciechów, to Mozolice, before undermining the left bank of the terrace on which Brzeźnica and Kozienice stand today. Beyond that it turned east in the direction of the Kochów – Świerże fords, before following a loop extending to between 1.5 and 2km east of today's channel. Gacki (1872) noted that there were references (if not precisely dated ones) concerning such a course of the old Vistula. In later centuries, the abandoned bed of the river was filled in and the oxbow lake became overgrown. However, along some sections it was repeatedly exhumated at times of high water, with the channel of the Vistula running parallel sometimes making use of the depression.

The great floods of the first half of the 12th century caused a significant northward shift of the river channel (such that the little town of Sieciechów switched position to the left bank) (Wąsowiczówna 1957; Kurzyp 1989). A flood in the 13th century destroyed the old town of Stężyca, the new one being located thereafter on the higher Pleistocene terrace. From the Middle Ages on, the boundaries of numerous administrative and political units existing in the valley of the Middle Vistula were delimited along the main river channel. The persistence of

the administrative and property boundaries was greater than the river course. By analysing the administrative divisions, network of parishes and boundaries of deaconeries or dioceses, we can indirectly reconstruct the course of the Vistula in a given period (the Middle Ages or the Renaissance). Thus, for instance, the historical sources record the split of the parish in Sieciechów, brought about directly by the significant shift in the river channel. The reach of the new parish with its seat in Stężyca enables conclusions to be made concerning the river's course.⁴

From the 15th century, most probably on account of the human impact within the Vistula drainage basin, including large-scale deforestation in the Carpathian Mountains and agricultural developments in the valley floor, the river began to change. It was wider and shallower, changed its channel more frequently, would subdivide into separate branches, and deposited more material in the channel, forming bars and islands. The biggest changes in the valley could be observed in the section below the gap (between the towns of Puławy and Stężyca) and the river gradually moved to the north-east. On the basis of archival documents, it is possible to reconstruct the main current of the river along its right bank. From Stężyca, the Vistula flows in a broad bend across the site of the village of Brzeźce (according to Długosz, it abandoned this channel in the 16th century, allowing the village to be rebuilt after two centuries, it having been destroyed in the 13th and 14th centuries. It then meanders westward towards Kozienice, but does not reach the edge of the terrace (with no historical sources confirming the presence of a Vistula port at this place).⁵ Below Kozienice, the river changes direction from NW to NE, between the fortified villages of Wargocin and Świerże circling in a wide bend undermining the right bank (Plit 2004). In spite of

³ There is an ongoing discussion among historians as to the location of the original defensive settlement of Sieciechów, as well as the siting of the castle of Kazimierz the Great. The sites under consideration are as much as 7km apart, with no clinching evidence as to which is right. There are no reservations about the location of the Benedictine Abbey (Wąsowiczówna 1957; Kalinowscy 1973; Kowalczyk 1994).

⁴ The map of Sandomierz Province from the second half of the 16th century, elaborated for the purposes of the Historical Atlas of Poland, contains the reconstructed boundaries of counties and parishes. In the vicinity of Kozienice, a part of these boundaries followed the then channel of the Vistula.

frequent floods and the greater suspended sediment load, the size of the Vistula meanders did not change. In subsequent centuries, the depression of the paleochannel was used by the small River Łacha. Today it is along the axis that a main drainage ditch runs.

The 15th-century course of the channel depicted on the map (Figure 1) changed dynamically, as in the flood of 1534 which left a large oxbow lake south of Zajezierze. This was still linked with both the Vistula and the Wieprz in 1564.

The fen soils of the fertile part of the valley were being deforested and brought under cultivation as early as in the Middle Ages and the Renaissance.⁶ An enormous influence on the development of the valley was exerted by the Benedictine Abbey. The monks cleared the forests, but then conducted a very careful and thorough development of the land thereby acquired for cultivation. They introduced numerous improved plant species and new methods of cultivation. For instance, until as late as 1688, the monastery was famous for its vineyards, although these had otherwise disappeared from Poland during the Little Ice Age. However, owing to a lengthy period of flooding, these vineyards disappeared (Gacki 1872).

At the turn of the 17th century, the Vistula flowed close to the Benedictine monastery in Sieciechów, thereby threatening the abbey. However, it then turned north towards Stężyca, and thereafter turned to the west. Around the year 1600 the river shifted channel, with the new one being farther to the

north-east. The shift in the channel to the lower fragment of the Wieprz river valley took place before 1678.⁷ In the second half of the 16th century the river along the Stężyca-Kochów section flowed some 2 km to the south-west of the current channel (Długosz 1841; Gacki 1872).

Detailed changes in the course of Vistula over the last 250 years can be reconstructed from cartographic sources. There are as many as four temporal cross-sections concerning the first 100 years, when, owing to the coincidence of numerous historical events, wars and political changes, shifts occurred in the settlement system and land use in the valley, while there was also a reduction, and ultimate abandonment, of river transport. During the same period, many catastrophes took place along the analyzed section of the valley—epidemics, famines, and above all, catastrophic floods (the largest ones being indicated by boldface numbers, in the years 1713–1714, 1736, 1737, **1749**, 1774, 1783, **1813**, 1838, 1839, 1840, 1844–45, 1850, **1852**, **1854**, 1855, 1867 and 1871 (Kurzyń 1989) and in **1934** and **2001**. Along the analyzed section of the river, catastrophic flooding was only noted in the 18th and 19th centuries (at Stężyca, which was one of the Vistula's main ports). From the 16th century on we have recorded both very high and very low water levels in the river. The non-embanked river frequently changed its channel, washing out banks and destroying cultivated fields, roads and settlements. In spite of this, no floodbanks were installed. All that was done between the 16th and mid-19th centuries was the strengthening with fascine and stones of the escarpment in Stężyca.

Major changes in the course of the river in the 18th and early 19th centuries were observed for the area around Stężyca. Each major flood gave rise to a reshaping of the valley. The high edge of the Pleistocene terrace on which the town had arisen was erod-

⁵ In Koźienica, Władysław Jagiełło commissioned the building of a bridge in Koźienice. This was floated down to Czerwińsk in the spring of 1410. Such a bridge could only have been built in a calm river port (and hence not directly on the Vistula). It is probable that the port in Koźienice was situated at the point the Zagożdżonka enters into the Łacha. (Stróżewska 1997).

⁶ A distinct increase in population density took place, starting with the 13th century. The colonisation concentrated on the more fertile and higher right bank of the Vistula. Between the 15th century and mid 17th century, the area experienced economic growth associated with brokerage in the cereal trade (as well as the trade in wood and salt). At that time there was an expansion of the town of Stężyca, playing the role of the main river port on this section of the river.

⁷ Documents relate to the administrative dispute that arose once the course had changed and the village of Borowa had been split by the Vistula. Even by the time of the map from Perthes, a part of the built-up area of this village is still seen to lie on the left bank.

ed intensively, such that the scarp retreated by c.1 km over the course of 100 years. The Gothic and Renaissance-style buildings were more or less destroyed in their entirety. All that remains today of the once centrally-located market square is its north wing. The river port was also destroyed. Figure 2 depicts the process involved along this section

of the river in the course of under 50 years. Attention is drawn to the ongoing process by which the navigable river grew braided, as well as to the changes in the nature of the valley occurring over a very short time.

The map of Stężycza District of 1759 shows the main current, running from the outlet of the Wieprz northwards, and then

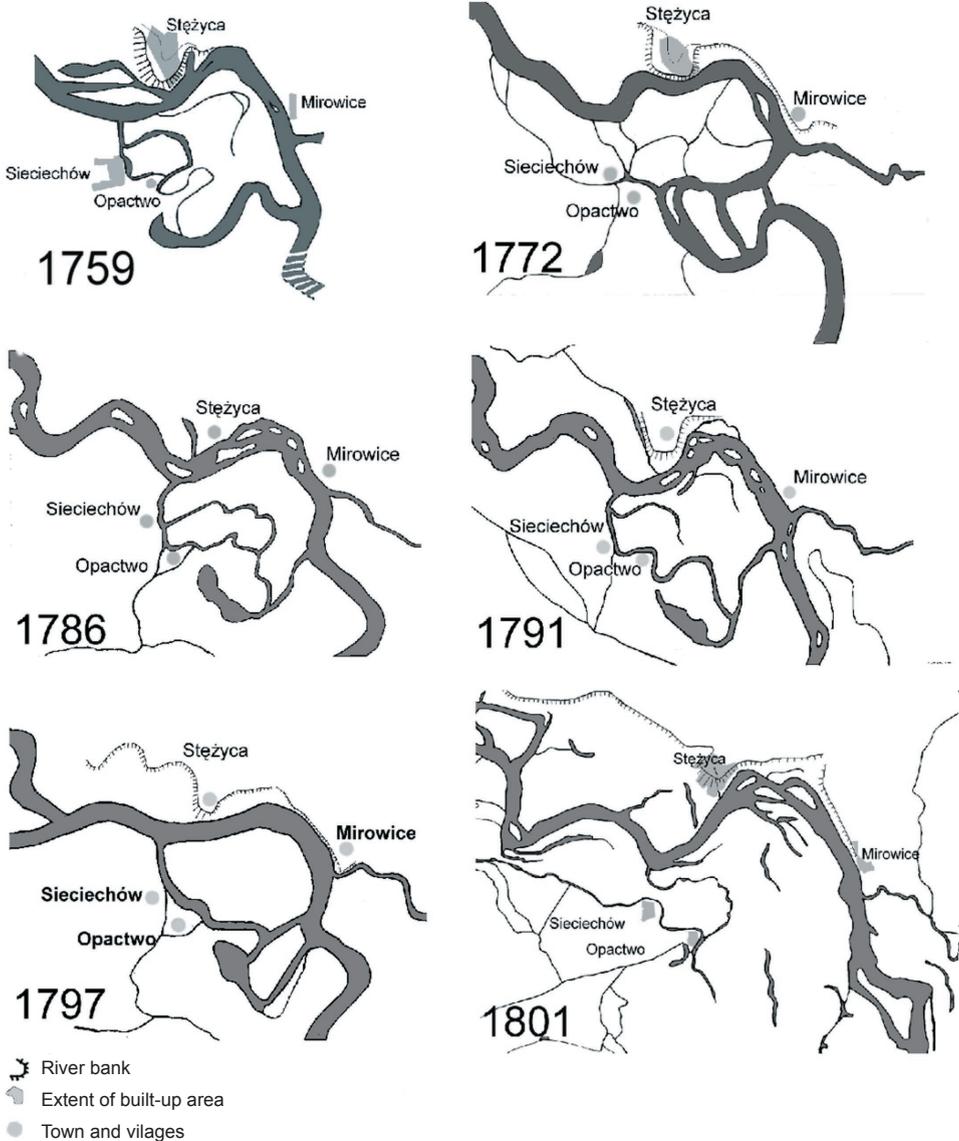


Figure 2. Dynamic of the Vistula River bed near Stężycza during 50 years of the 18th century.

with a bend towards the west (very close to Stężycza). In addition the map shows the appearance of an arm of the Vistula, with a width equal to that of the main channels, between Zajezerze and Sieciechów. This is what remains of the old channel washing away the Benedictine abbey (and mentioned in the monastic chronicles). This map also documents the existence of a network of parallel channels and oxbow lakes.

Zannoni's map depicts the river after a flood. The Vistula was still a meandering river as of 1772. Below Stężycza well-developed meander bends existed, one of these already having had its meander neck cut through. The Vistula split into numerous arms and branches, especially to the north of Stężycza (1762). At that time, the main channel flowed very close to Stężycza, cutting into the edge of the terrace, to pass with gentle bends around the fortified Wargocin. The map from Czaykowski (before 1786) notes the functioning of two parallel channels of the Vistula over the length of more than 20 km (from Brzeźnica almost to the mouth of the Radomka), as well as a system of parallel channels and a large oxbow lake left as a trace of the meander to the south of Stężycza (Figure 3a). As a result of the enhanced accumulation of sediments in the river-bed, an ever greater number of sandbanks and islets appeared. The Vistula was cutting intensively into the right bank, destroying structures in Stężycza, between which town and Wargocin it formed numerous meanders, before flowing via a broad arc along the right bank.

The reconstruction of the course of Vistula as it appeared in the last years of the 18th century is based upon the map of Karol de Perthes (Figure 3b). The main river channel is meandering, and the numerous developing small bends demonstrate the tendency towards an increase in sinuosity. The traces of floods may, however, be evidenced by the numerous branches (Bronowice-Opatkowiec), joining both among themselves and with the main channel (Borek-Opactwo-Łoje). The arms of the river close to a straight course could be interpreted as relief channels, while those of the winding course correspond most

probably to the 'inundated' older riverbeds. That is why the floodplain of the Vistula in this area developed islands separated by numerous river arms.

At the turn of the 19th century a change in the development of the river course took place, apparently the result of a combination of natural and historical conditions. Very significant changes in the riverbed took place, in spite of the absence of large floods in this period. The braiding of the Vistula can be seen through the increased linearity of its channel as compared to 10–12 years earlier, as well as through the presence of numerous central bars, especially on the Puławy-Wróble stretch. Fresh sandy deposits appeared in many places along river banks and over large areas (Figure 3c). Between Kazimierz and Wargocin, the Vistula ceased to meander, and it no longer flowed along parallel braided channels.⁸ The 1801 map from Meyer von Heldensfeld depicts a system of floodbanks for the first time along this section of river stretching from Sieciechów almost as far as Świerże. The siting of reinforcement points to the section of the Vistula valley along which avulsion was most frequent and/or gave rise to the most damage. The determination of the local community to do something about the matter is indicated by the fact that work on the embankments began in a very 'unfavourable' period (in the sense that there was political turmoil, frequent wars and uprisings, constant changes in local administrations and an impoverishment of the people). The threat posed by the increasingly uncontrolled river must have increased markedly in the period. In the years 1800–1840, four catastrophic floods brought significant changes to the valley bottom (Figure 3d). The greatest flood occurred in the Vistula valley in 1813, causing vast destruction. The level of the water (as measured by the Benedictine

⁸ The situation looked rather different in the two neighbouring sections of the valley. The 1797–1801 charting by Meyer von Heldensfeld still registers river meanders (at the level of the confluence with the Kamienna and Iżanka, as well as downstream of the confluence with the Radomka).

monks) rose by 22 feet and the high water along the Vistula and Wieprz was associated with the establishment of a large lake. Part of Borowa village lay on an island, the greater part of it had been destroyed by the flood. Villages and small towns on the left bank also suffered greatly, though the flood spared Stężyca. The peak high water also exhumated the oxbow lakes near Gołab, Sieciechów and Zajezerze. Numerous villages were completely annihilated. Likewise, Wargocin, situated on the right bank, was also destroyed, only the church and a couple of structures remained. The Quartermaster's map also documents changes in the river course. The Vistula flowed by Wargocin via several arms, around small islets and shallows. The Quartermaster's map documents the large area of unvegetated sand deposited within the Vistula channel and on the flood plain, as well as at the junction of the Vistula and Wieprz in time of flood. The embankments between Gołab and Borowa (preventing the Vistula channel from being shifted into the confluence section of the Wieprz) had been achieved by 1830 (Figure 3d). The bridgeheads in Puławy and Dęblin were also strengthened, while the two banks of the Vistula near the Iwangozod stronghold (now Dęblin) were fortified.

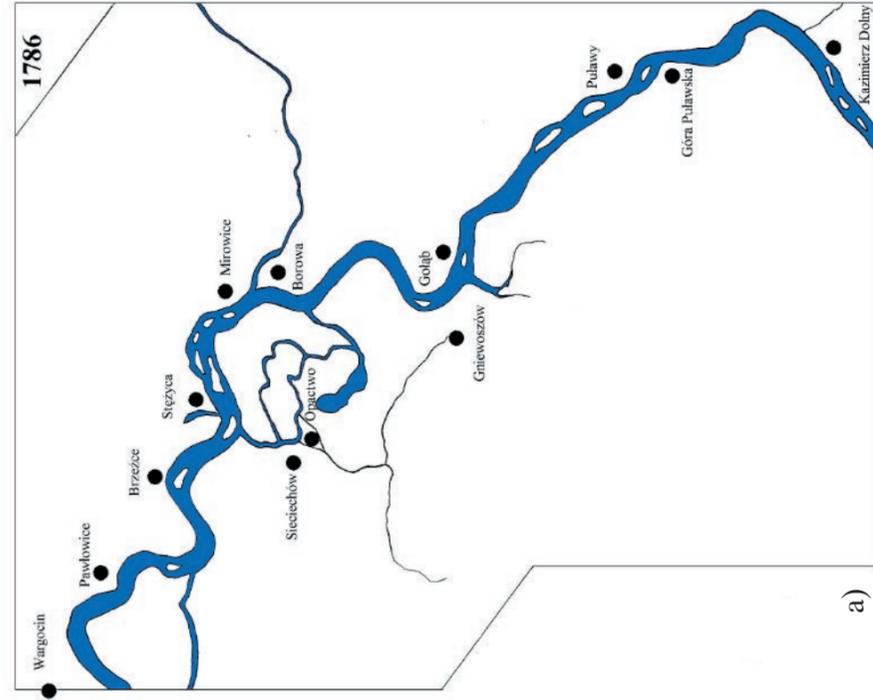
Embankments were built on the lower-lying left bank of the Vistula in the years 1846–1856. These extended from Góry Puławska to Świerże, and so were 26.7 km long and 22 feet (6.4 m) high. Their construction was followed by an enhancement of right-bank erosion, such that, for example, the years 1867 and 1871 brought destructive activity in Wargocin, so that the inhabitants were required to transfer to the neighbouring village of Wróble. The effect was necessary work to embank the right bank too, though this proceeded at a sluggish pace, such that it was completed after World War II (Figures 3e, 3f and 3g). Unfortunately, there was (and is) pressure on the part of farmers to restrict as far as possible the area in which the river might freely shape its own channel. As a result, successive ever-taller reinforcements were added, closer and closer

to the main channel. The bed is curtailed, the flow becomes straighter and straighter, side branches and oxbows stand out and the distance between the embankments is shortened.⁹ Villages and roads are built on the flood terrace, even in places where the main channel flowed as recently as 100 years ago. Cultivated fields and orchards are more than once found in the area between the banks. The overall result is, however, to increase considerably the risk of flooding and large economic losses caused by peak flows. The embanking of the river on both sides has hindered the surface runoff of precipitation and meltwaters. Many areas have become flooded secondarily and this process has necessitated drainage of the terraces above the level of the floodplain. The Łacha stream and lower sections of the Vistula tributaries have been turned into deep drainage canals (Figures 3g and 4).

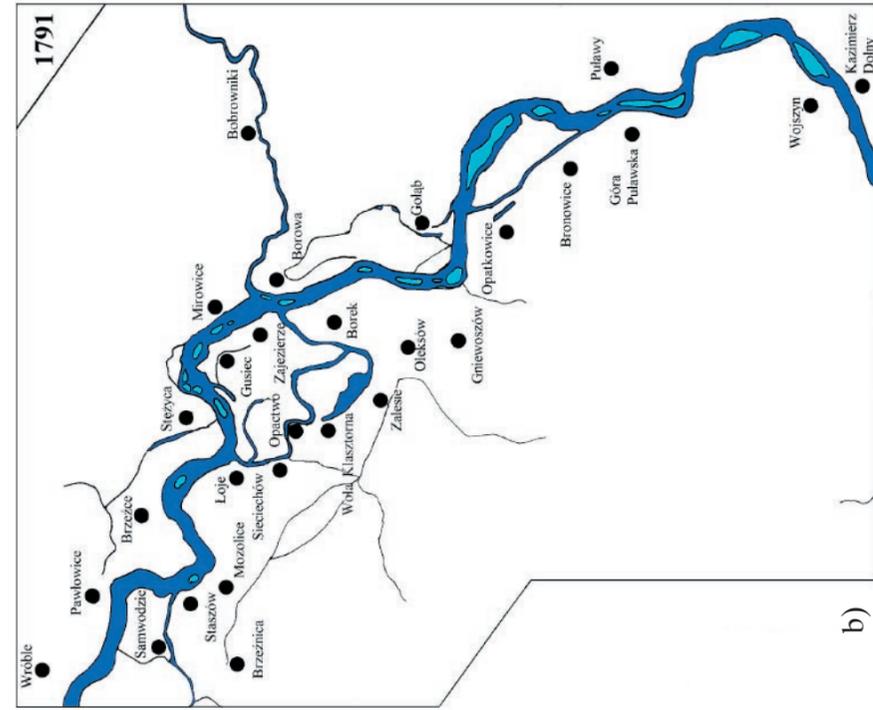
The river accumulated sediments within its channel (sandbars, islets and new arms appeared). The Vistula became ever shallower and wider, while the fluctuations in water level through the year became greater and more frequent. Navigation ceased, not only for political and economic reasons, but also for technical ones.

Along the 55 km section of the river analysed here, the sole stretch with a channel persistent throughout the period of 230 years was just one and half kilometres long (Figure 4). Along the deeply-incised gap section (Kazimierz Dolny–Puławy), the narrowness of the valley limited the opportunities for channel-shift, as well as for any division into different channels. Thus the Vistula flowed in just one channel throughout the historical period, with small modifications to the course only being noted where the valley is wider. However, following its emergence onto the plain from the narrow entrance to the gap section, the river shaped its valley freely. It meandered, became multithreaded,

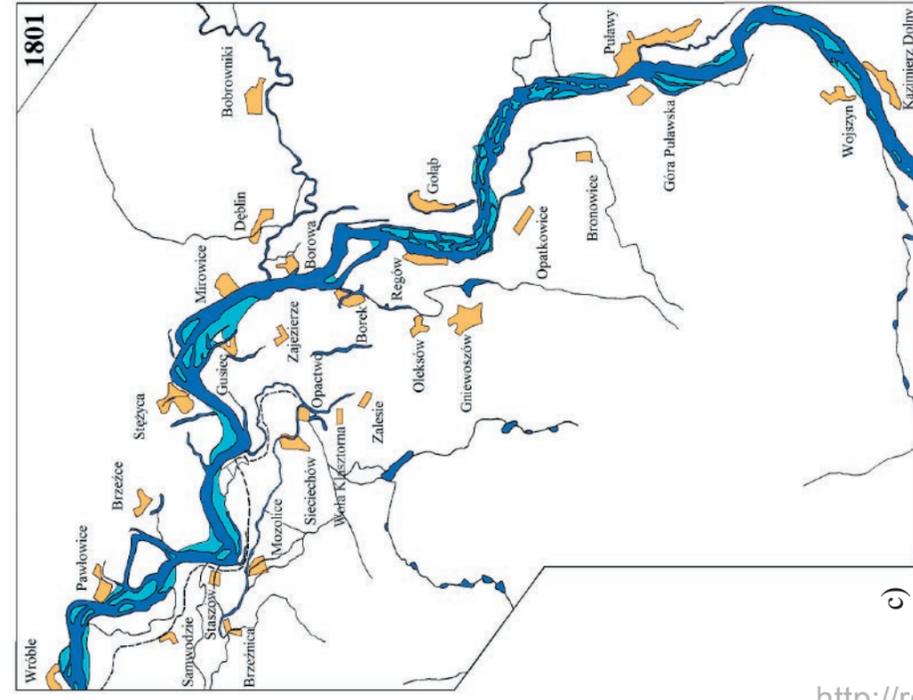
⁹ Along some sections we today have two or three parallel sets of floodbanks (e.g. between Gołab and Borowa, or S of Puławy where the flood terrace has been narrowed by 1.5 km).



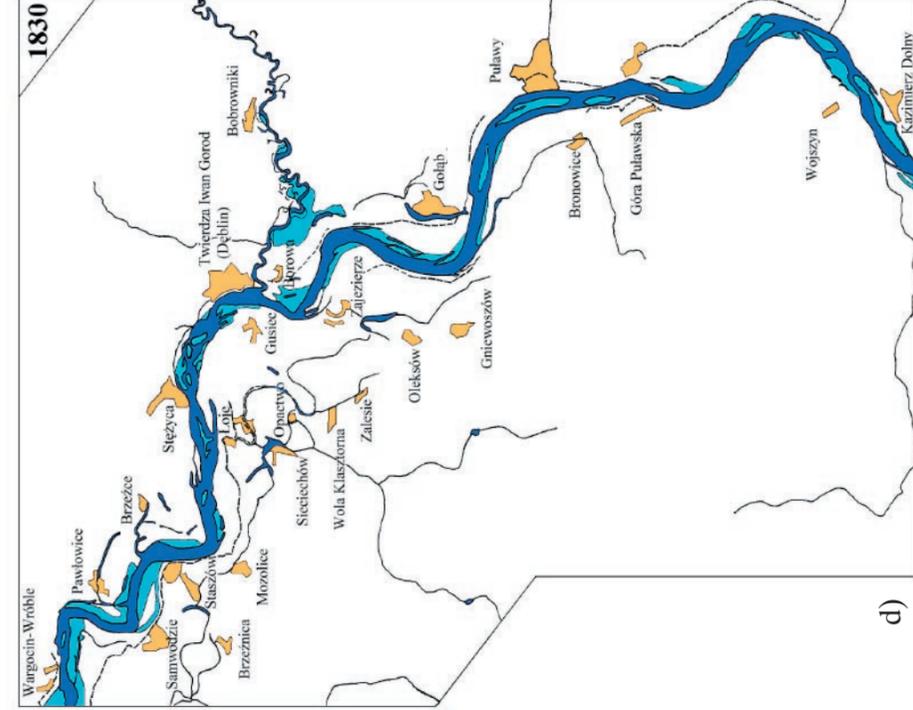
a)



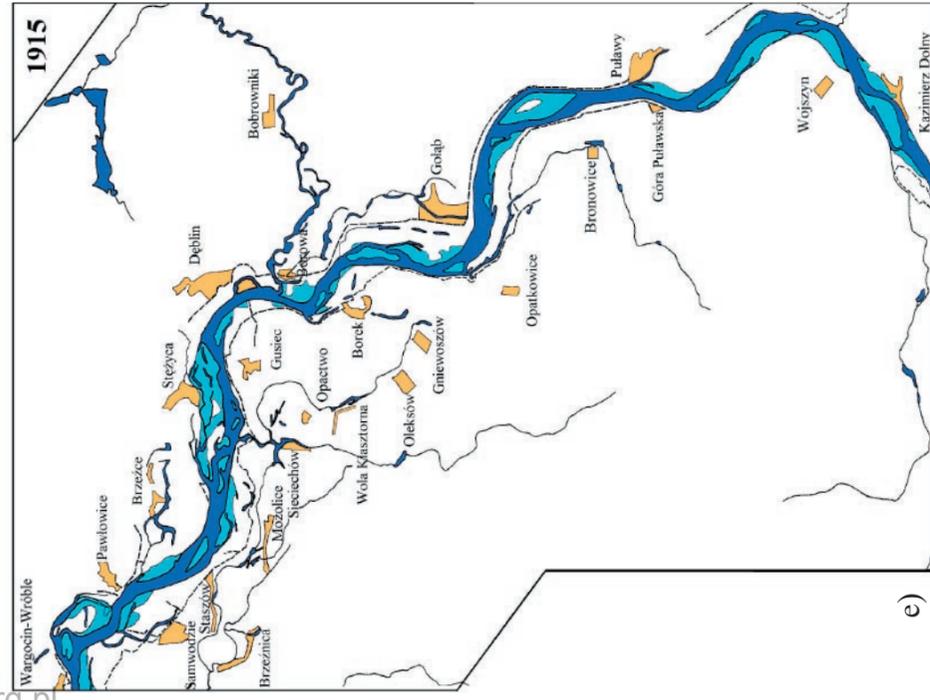
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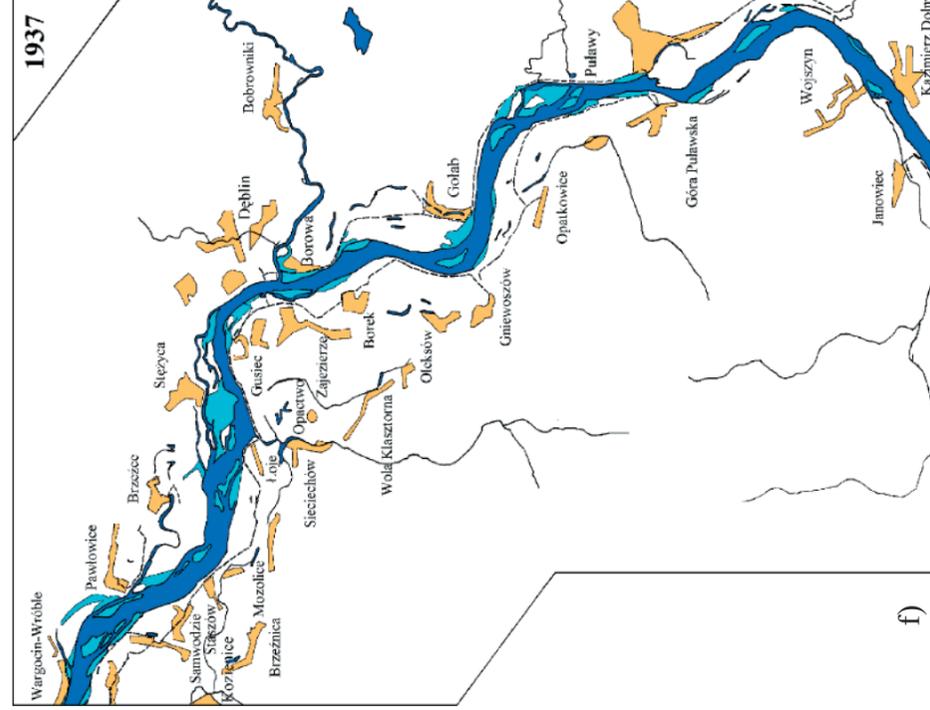
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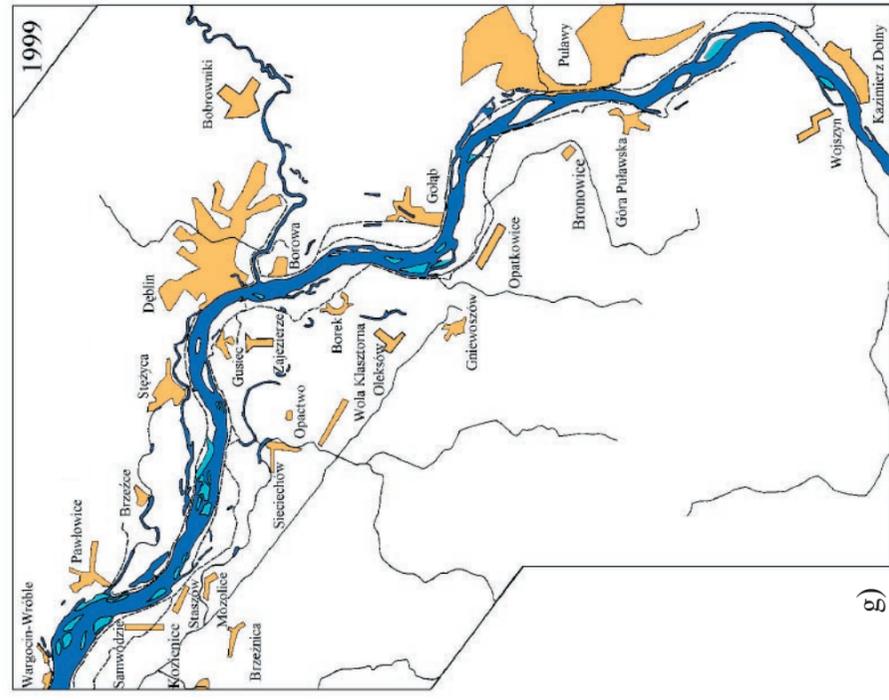
d)



e)



f)



g)

Figure 3a-g. The Vistula and its tributaries, from 1786 to 1999.

0 5 10 km

- Present river channel
- Non-stabilized sand sediments
- Town and villages
- Flood protection walls

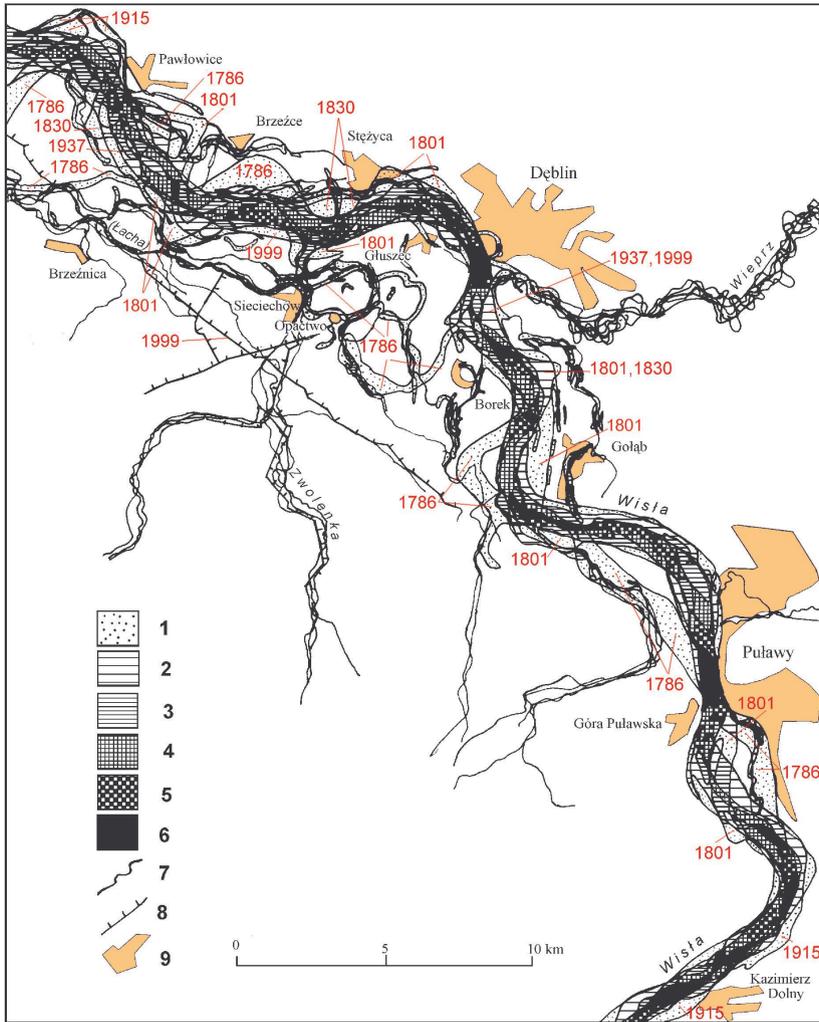


Figure 4. Changes of the Vistula River bed based on:

1—one map, 2—two maps, 3—three maps, 4—four maps, 5—five maps, 6—six maps, 7—small river, 8—channel, 9—the extent of built-up area in 1999.

often changed channel and thus deposited fertile alluvia over the entire Holocene plain. A brake was put on this process when the embankments began to be constructed on both sides. The gradual shift of the river to the north-east occurred. It made use of the entire Holocene valley, flood undercutting the higher terraces alternately on both sides. By comparing Figures 1 and 4 we

can determine those sections of the valley especially prone to erosion over recent centuries. The cartographic material documents the recession of the edges of these sections due to lateral erosion: in Wargocin by c.500 m, and in Steżycza by c.1000 m (in the years 1759–1801). This process, resulting primarily from catastrophic events, was not, of course, distributed uniformly over time.

FINAL REMARKS: CAUSES OF RIVER CHANNEL AND VALLEY CHANGES

The historical analysis carried out suggests that up until the late 18th and early 19th centuries—the section of the River Vistula in question was mainly affected by natural factors, especially the fluctuations of precipitation, although the channel was transformed at times of catastrophic floods. From Mediaeval times, the Puławy–Kozienice section of the river moved steadily NE (in accordance with the Coriolis force) and finally followed the avulsion to the lower fragment of the Wieprz Valley (in the second half of the 17th century). The Vistula was a meandering river throughout this period, and the sizes of the bends did not change for several centuries. This points to limited changes in the river regime and sediment load. The whole of the fertile Holocene valley floor was deforested and put to agricultural use (mainly in the cultivation of crops or establishment of meadows). Where land was owned by the Benedictines of Sieciechów, much of it was given over to vineyards and orchards. There was also successive felling of forests on nearby elevated areas.

Changes in the valley took place steadily in the second half of the 18th century. The first section of the Vistula to cease to meander and take on the character of an anastomosing river was that between Kazimierz and Kozienice. In the adjacent (30-km) Józefów–Kazimierz and Kozienice–Magnuszew sections, the river was still meandering in places as late as in the 19th century, flowing along certain sections via several interlinked branches (as an anastomosing channel). Only at the end of the 19th century, did the transformation into a typically braided-type channel take place.

The change in the character of the river was doubtless caused by many different factors. It may have been the result of processes upstream. Sometimes it may have occurred after a considerable time delay. The factor most often mentioned in accounting for the change in the character of the Vistula channel is the destruction of forests in both the river

valley and over its drainage basin. Changes in forest cover in a basin bring about changes in a river's regime after a certain time interval. This factor undoubtedly affected the middle section of the Vistula valley, though probably was not a leading one. In summary:

- The alluvia of the valley floor were deforested and put to agricultural use as early as in the Middle Ages. It is probable that incursions by the Jatvingians, Lithuanians and Tartars—who effectively cleared the entire region in the 12th–14th centuries, were responsible for a shortlived regrowth of forest, prior to a new wave of settlement that renewed management in the valley.

- On the surrounding plateaus, the exploitation and reduction in forest area took place without interruption from the late Middle Ages through to World War II. In the basin of the Middle Vistula, the most intensive cutting occurred in the 16th–18th centuries. In the 19th and 20th centuries, the area of forest declined a little, but the work of foresters allowed felled areas and clearings to be replanted, while whole forests were planted with a view to dunes and steep slopes being stabilised against erosion. The density of the tree stands also increased (Plit 2003).

- The historical analysis carried out for the middle section of the Vistula Valley did not confirm the dominant influence of deforestation in the Carpathians (Soja 2002; Pietrzak 2002), where the change in the character of the river channel was concerned.

- Causes of valley changes should also be sought in the increased precipitation and climatic cooling associated with the 'Little Ice Age' (Maruszczak 1997), which produced more frequent flooding and an increased role for ice jam floods. The accumulated historical material confirms the influence of this factor, though floods of comparable size – proving destructive in the valley and linked with major movements of the Vistula channel – were also recorded in the 12th, 13th, 15th and 16th centuries. Alas, the chroniclers do not tell us if these were ice jam floods or not.

The causes of the increasing sediment load (and hence the causes of the increased

deposition on the flood plain and shallowing of the channel) need to be considered in relation to intensification of human activity. The main cause of the greater loading of the river with sediment was the increased soil erosion reflecting changes in the methods of cultivation, and above all increased interest in the growing of root crops, especially potatoes (then becoming the staple food plant) (Stupik 1973). Rows of potatoes and beets dug round several times in the course of the growing season were associated with a removal of the protective sward layer from the soil. Furrows facilitated the ablation of soils and hence a major intensification of surface erosion. Furthermore, the increasingly widespread practice of crop rotation in the Polish countryside, cessation of fallowing for some land, and decisions to cultivate waste ground (and even quite steep slopes) brought about increased gullying and soil sheet erosion. An important further factor in enhancing erosion was the crossing of the uplands by an increasingly dense road network (Pietrzak 2002; Soja 2002).

A huge and under-appreciated influence was exerted by the complete embanking of the Vistula valley (in the middle of 20th century), some of them were also on the separate braids. This fixed the braided nature of the river channel, irrespective of possible changes in the river regime, sediment load and changes in land use in the basin. The capacity of polluted waters to purify themselves was reduced. Another result was the dropping of the entire load of accumulated material on the land between the embankments, resulting in a raising of the river channel above the flood terraces (which partly thus became marshy and were left in need of draining).

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THE LANDSCAPE-ECOLOGICAL PLAN IN THE PROCESS OF RURAL LANDSCAPE DEVELOPMENT SUPPORTED BY SAPARD¹

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Abstract: The aim of this article is to point to the possible interface between landscape-ecological planning and programmes supported by the European Community. Priorities and measures embraced by SAPARD were used in a landscape-ecological plan applied at the local level. Five methodological steps based on the LANDEP methodics, i.e. Landscape-Ecological (L-E) analysis, L-E synthesis, L-E interpretation, L-E evaluation and L-E proposals, were applied to prepare the Proposal for optimal utilization of the study area. Being a compulsory part of territorial planning, the L-E plan is a way in which to include measures resulting from Common Agricultural Policy (CAP) reform into landscape utilization proposals in Slovakia.

Key words: SAPARD, landscape-ecological plan, land use, landscape-ecological proposals, Slovakia.

INTRODUCTION

'In the complex interplay of different forces and pressures which give rise to environmental problems, the role of land-use planning and management is crucial. This covers a wide range of decisions, usually at local and regional level, determining the character and intensity of land use and activities which may often have a major impact on environmental conditions' (European Commission 2001).

In the last decade, considerable attention has been devoted to projects focused on systemic solutions to environmental problems within the framework of geoecological research in Slovakia. Several meth-

odological procedures concentrating on the processing and assessment of geoecological information have been developed. Some of them (e.g. processing of territorial systems of ecological stability, environmental impact assessment, optimal spatial arrangement and functional use of territory) have also been included within the current legislation of the Slovak Republic. The results of detailed analyses and assessments of defined problems often remained in the form of theoretical drafts, without implementation. This process stagnated due to a lack of finance above all.

Land-use planning and management decisions in the Member States of the European Union (EU) have an important influence on the environment. The Community plays the role of encouraging and promoting effective planning and adequate policies at the

¹ Special Accession Programme for Agriculture and Rural Development.

local and regional levels, especially through different programmes and the Structural Funds (European Commission 2001).

The aim of this study is to evaluate the possibility of the systemic solution of environmental problems (pursuing selected methodological procedures) being linked with the priorities and measures expressed within the SAPARD framework.

The study area is situated in the Trnavska Pahorkatina Hill land (northern part of the Danubian Lowland), one of the most fertile regions of Slovakia. It covers a strip about 1.2 km wide and 3 km long, in which the majority of the landscape elements typical for the region are represented. The central part of the territory is occupied by the Ronava Reservoir, the dam of which lies about 400 metres away from the motorway connecting the cities of Bratislava and Trnava.

METHODOLOGY

The elaboration of the landscape-ecological plan for the study area has been based on methodological procedures of ecologically-optimal landscape use within the framework of surveys and analyses for the territorial plan of a municipality (by Hrnčiarová et al. 2001), after some adaptation. The plan aimed to establish an optimal functional use of this area, taking into account its landscape-ecological, cultural, historical and socio-economic conditions. The study has been conducted through five methodological steps based on the LANDEP methodics (Ruzicka and Miklos 1982), i.e. Landscape-Ecological (L-E) analysis, L-E synthesis, L-E interpretation, L-E evaluation and L-E proposals and measures.

The L-E analysis consisted of the collection of input data, the homogenizing of content and scale, the compilation of the preliminary geoecological map, the typifying of preliminary units, the choosing of research points for each geoecological unit (47 in total) and the conducting of field research, in the course of which relief forms, inclination, altitude (a.s.l.), soil characteristics (type,

colour and thickness of soil horizons, soil textures, skeleton content, soil structure, and hydrocarbon content) and land use were described. At this stage, use was made of the following maps and publications: topographic maps and orthophotomaps, Map of soil types and soil texture by Fric (1961), the Map of soil-ecological units by Fric (1974), the Map of technical adjustments of the environs of the Ronava Reservoir by Svec (1983)², geomorphological analyses (Stankoviansky 1993), biogeographical analyses (Kopecka and Ruzek 2001), analysis of avifauna (Ruzek and Senko 2002; Trnka et al. 2002), analyses of important landscape and ecological structures (Izakovicova et al. 2001), and analyses of stress factors (Izakovicova et al. 2001).

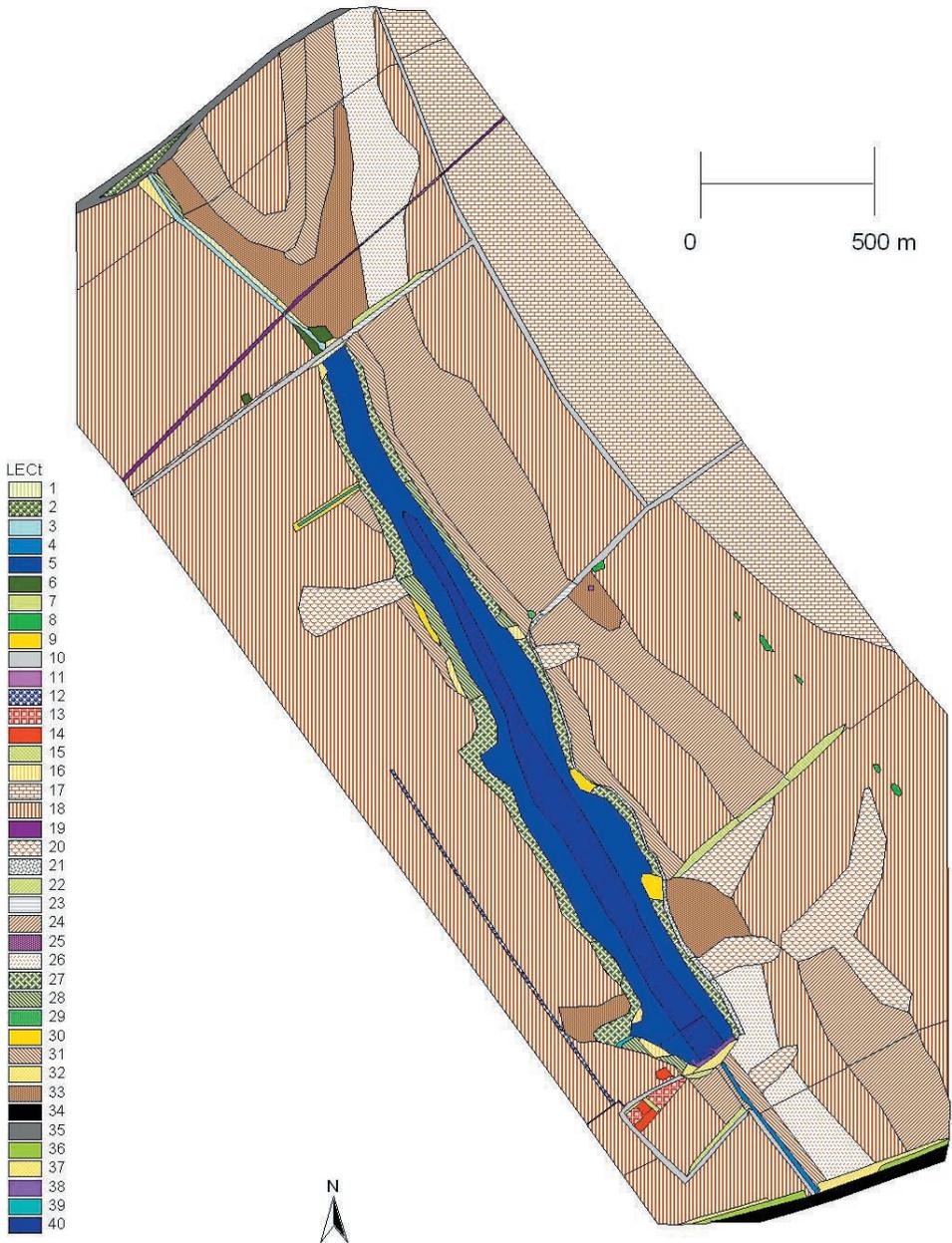
At the stage of L-E syntheses, homogeneous areas (so-called Landscape-Ecological Complex Types, LECTs) were created, characterized and presented on a map (Map 1). LECTs are defined as areas having the same combination of abiocomplex type (Trembos 1994) and contemporary landscape structure.

At the interpretational stage (L-E interpretation), the threatened and threatening phenomena and their sources are indicated and assessed, and a map of environmental problems (Map 2) is produced. The map represents threats to the landscape and its component elements as a consequence of stress factors.

At the evaluating stage (L-E evaluation), the landscape indices are set against the requirements of society, and the measures and activities from SAPARD applicable in the chosen territory are selected. This step concentrates on estimating the adequacy of the land use in the study area, taking into account L-E complexes, proposed activities and use and environmental limits.

At the final stage (L-E proposals and measures), an optimal means for the spatial utilization of the landscape is formulated. The results of the decision-making process are expressed on a map, the unsuitable ac-

² All maps cited are at the scale 1:10 000.



Map 1. Landscape-Ecological Complex Types (LECTs₁₋₄₀)
For definitions of LECTs see Table 5.

tivities being excluded and measures for optimal functioning of the proposed landscape structure (i.e. measures ensuring ecological stability and palliating the impact of stress factors) elaborated. The output is presented in the form of a proposal for the optimal utilisation of the study area (Map 3).

SAPARD³

In the case of the Slovak Republic, the aims with regard to SAPARD were as set out in the Plan of Development of Agriculture and Rural Areas of the SR for the years 2001–2006. Qualified for participation in the Programme are all kinds of legal forms of agricultural businesses⁴ seated in the SR (except state-owned companies), municipalities, non-profit organizations and other

³ Detailed information on SAPARD is available at <<http://www.mpsr.sk/slovak/dok/sapard/english/sapard.htm>>

⁴ Agricultural co-operatives, commercial companies, private farmers, natural persons engaged in business activities, associations of entrepreneurs, land associations.

business entities. Priorities and measures that qualify for support under SAPARD are summarized in Table 1.

In evaluating the projects, the linkages to the other competent projects under SAPARD are taken into account. For this reason, it is recommended that the potential users of SAPARD funding should collaborate in preparing their projects with other partners pursuing particular conditions in each region, and not to work in isolation. The Landscape-Ecological Plan can be of assistance to the applicants in this process.

RESULTS

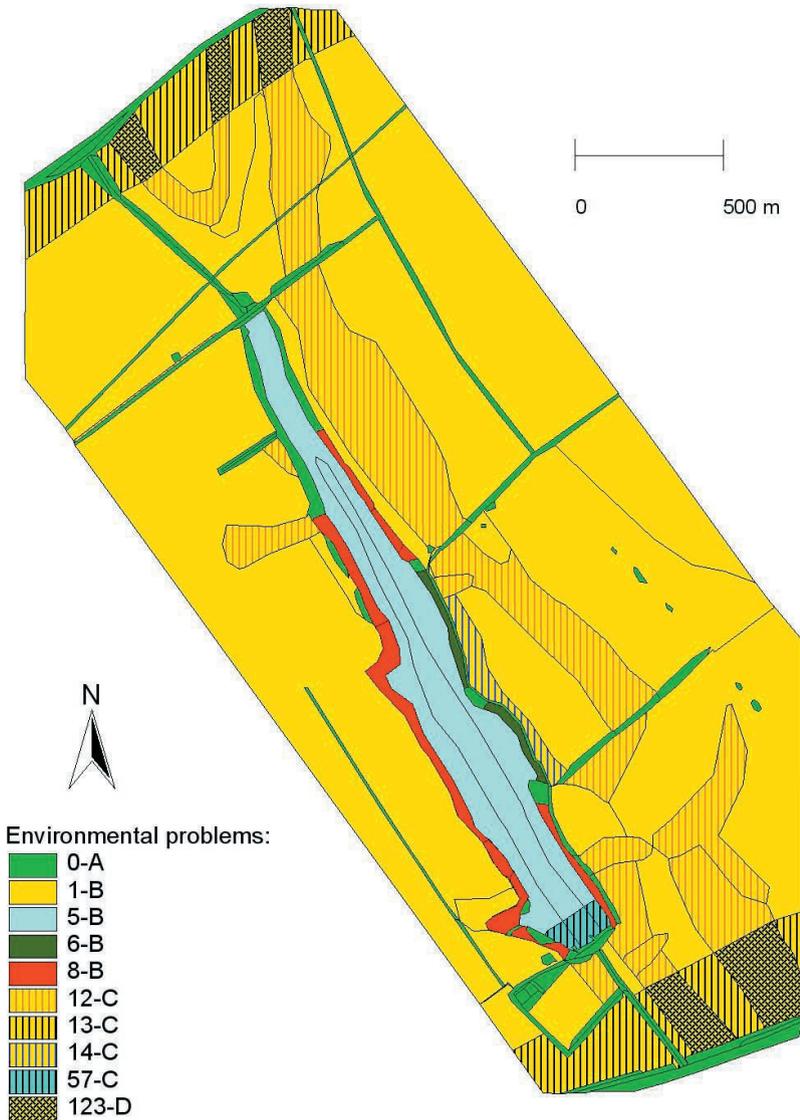
LANDSCAPE-ECOLOGICAL ANALYSIS

Abiotic components. Abiotic landscape components identified during the field research are summarized in Table 2.

Climate. The territory can be classified as a warm area with a moderately dry climate and mild winter. Average annual air temperatures oscillate between 9 °C and 10 °C and the average annual precipitation total is 560 mm. The prevailing

Table 1. Priorities and measures qualified for SAPARD support

Priorities	Measures
Improvement of the agricultural production sector, including the food industry	<ol style="list-style-type: none"> 1. Investments in agricultural firms (sheep, poultry-breeding, fruit and vegetables, medicinal and aromatic plant growing, irrigation) 2. Improvement of the processing and marketing of agricultural and fish products (investments in the industry processing meat, poultry, milk, milk products, fish and fish products, fruits, vegetables and the production of ready-made meals) 3. Support for the foundation of outlet organizations of producers
Sustainable development of rural areas	<ol style="list-style-type: none"> 4. Diversifying activities in rural areas <ul style="list-style-type: none"> —investments other than in infrastructure, —investments in infrastructure, which do not generate any substantial revenue 5. Forestry 6. Procedures of agricultural production oriented towards environmental and landscape protection (five pilot projects in selected regions of Slovakia) 7. Land adjustments
Development of human activities	<ol style="list-style-type: none"> 8. Development of human resources (training courses and programmes) 9. Technical assistance (studies, programmes of microregional development, territorial-planning documentation of municipalities and microregions).



Map 2. Environmental problems: 0-A—Areas without environmental problems (A category), 1-B—Agricultural soil of the 1st quality threatened by wind erosion, 5-B—Reservoir with incidental microbiological pollution, 6-B—Ecologically important bank vegetation locally threatened by undermining, 8-B—Endangering of protected birds by hunting (B category), 12-C—Agricultural soil of the 1st quality threatened by wind and water erosion, 13-C—Agricultural soil of the 1st quality threatened by wind erosion and inundated periodically, 14-C—Agricultural soil of the 1st quality threatened by wind erosion and affected by air pollution near heavy roads, 57-C—Proposed biocentre with incidental microbiological water pollution partially affected by noise near heavy roads (C category), 123-D—Agricultural soil of the 1st quality threatened by wind and water erosion and affected by air pollution near heavy roads (D category).

Table 2. Abiotic landscape components

Landscape component	Code	Characteristics
Relief	1	Relief forms created by recent and subrecent fluvial processes—river valley
	2	Relief forms created by aeolian processes—plains
	3	Relief forms created by slope processes—dells and dell depressions
	4	Relief forms created by slope processes—transport slopes
	5	Relief forms created by slope processes—accumulation slopes
	6	Relief forms created by anthropic processes—planated forms
	7	Relief forms created by anthropic processes—elevated forms
	8	Relief forms created by anthropic processes—deepened forms
Inclination	1	less than 3°
	2	3–7°
	3	7–12°
	4	more than 12°
Soil type	1	Modal chernozem
	2	Modal calcareous chernozem
	3	Modal calcareous chernozem, accumulated form
	4	Cultizemic chernozem
	5	Cultizemic calcareous chernozem
	6	Cultizemic calcareous chernozem, accumulated form
	7	Cultizemic calcareous chernozem, erosional form
	8	Gley chernozem
	9	Initial anthrozem
	10	Recultivated anthrozem
	11	Subhydric soil
Soil texture	1	Loam
	2	Silty-loam
Subsoil	1	Alluvial sediments
	2	Aeolian sediments (loess)
	3	Anthropogenic substratum

winds are currents from the northwest and southeast. The average wind speed a year is 3.2 m/s.

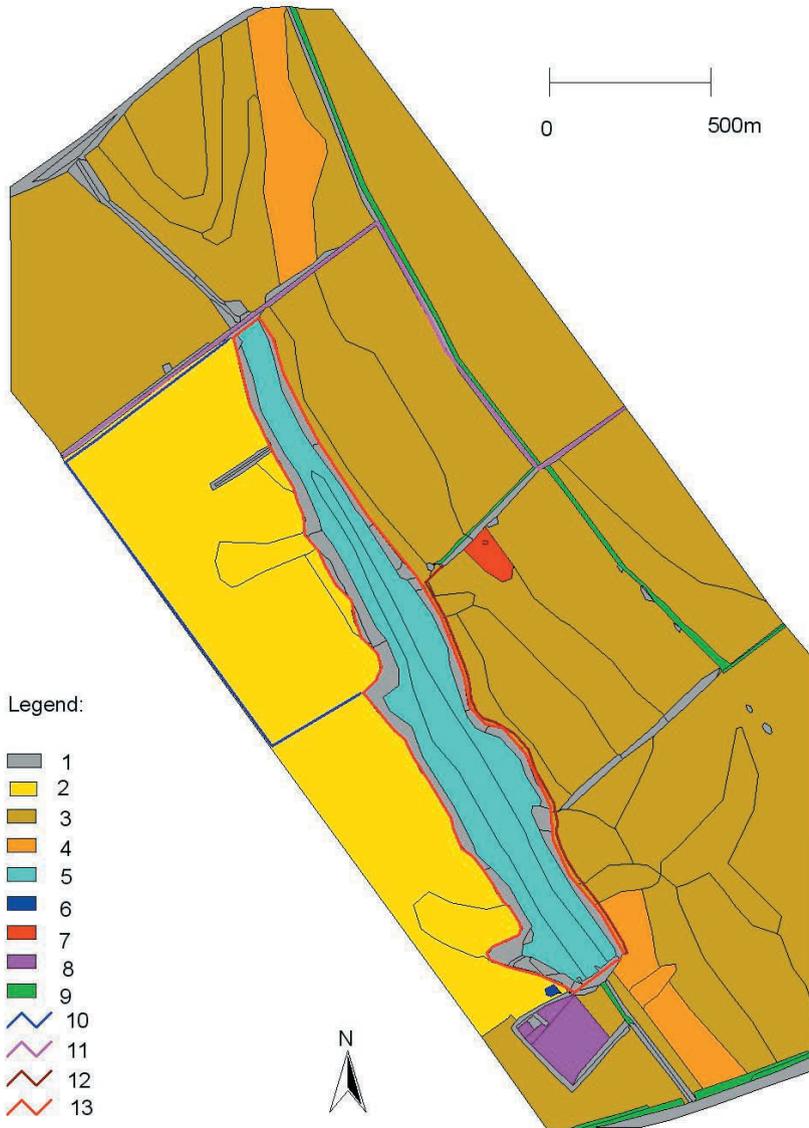
Water. The territory of interest is a part of the Ronava River basin. Apart from this river, the important elements of the hydrological network are channels (feeding and draining), which regulate the amount of water in the Ronava Reservoir.

Biotic components.

Vegetation. Physiognomy, floristic composition and rate of synanthropisation have been examined on the water basin shores with willow and willow-poplar growth, non-forest woody vegetation, perma-

nent herb cover, reed beds and ruderal associations. Among 108 plant species identified in the study area, hemicryptophytes prevail to a significant extent (Kopecka and Ruzek 2001). The share of recorded synanthropic (weed and ruderal) species is about 34%.

Fauna. The Ronava Reservoir, along with its shore growth, forms an important locality amidst agricultural plots, which attracts waterbirds and shorebirds especially. So far 91 vertebrate species have been found there. The class of birds is the best represented, with 73 species. Five species of amphibians, 1 species of reptile and 12 species of mammal



Map 3. Proposal for optimal utilization: 1—Preservation of secondary landscape structural elements, 2—Growing of vegetables, 3—Growing of cereals, oil plants and legumes, 4—Growing of permanent and perennial cultures, 5—Fishing, 6—Modernisation of irrigation system, 7—Construction of agro-tourist facility, 8—Construction of processing facilities, 9—Planting woody vegetation, 10—Expansion of irrigation system, 11—Cycling, 12—Finishing of hard-surfaced road, 13—Proposal of territorial protection.

have also been identified (Trnka in Iza-kovicova et al. 2001, Ruzek and Senko 2002).

Land use.

Land use changes. In recent decades meadows and pastures have completely disappeared from the study area and its environs. The remnants of original forest have also been removed. On the other hand, the reservoir with its shore growth is a new element in the landscape structure. Small-scale fields have been transformed into large blocks of fields and this process has been accompanied by elimination of non-forest woody vegetation. In contrast, some remains and parts of the original shore growth have extended. The retention reservoir was constructed on the Ronava River in the years 1965–66, in order to improve the irrigation of fields. Accumulation of a large amount of water in the new area determined the development of a new biocentre important for many species, which did not occur in the area before the construction of the reservoir.

The present land use. The prevailing part of the arable land on the right shore of the

reservoir lies on a relatively flat surface with an inclination below 3°. The arable land is worked in large blocks—the size of user parcels in the study area ranges between 30 and 300 hectares. The dominant crops grown here are: winter wheat, rapeseed, and sunflower, and to a lesser extent—spring barley, maize and soybeans. The tillage is performed about once in three years to a depth of 25–28 cm. Depending on the crop, the plots are treated with pesticides at least twice a year, in the case of growing oil plants desiccants are also used where appropriate. The area of the reservoir, used mainly for fish breeding, changes throughout the year. At times of the maximum water table per elevation of 137.4 m a.s.l., 38.89 hectares is inundated. The water table of the reservoir exploitable for fish breeding which is maintained through most of the year at an elevation of 136.3 m a.s.l., when 27.9 hectares are inundated. The irrigation system has been constructed on the right shore of the reservoir over an area of 355 hectares.

In the course of field research, we identified 22 elements of contemporary landscape structure (CLS) (Table 3).

Table 3. Elements of contemporary landscape structure identified in field research

	Surfaces	Lines	Points
Vegetation	1. Patch non-forest woody vegetation 2. Willow waterside formations 3. Willow-poplar waterside formations 6. Hygrophilous tall herb communities 7. Reed beds 8. Mesophilous herb communities 9. Large scale arable land	4. Tree lines	5. Solitary trees 21. Ruderal communities
Water	12. Water bodies	10. Water course 11. Canal 19. Irrigation system	18. Water tower 20. Dam
Communication infrastructure		13. Electric wiring 14. Motorway 15. Main road (1st class) 16. Side road (3rd class) 17. Field road	22. Solitary buildings

Landscape protection and important landscape structures. There is no legally-protected locality within the study area. Floral analysis (Kopecka and Ruzek 2001) shows that, in the environs of Ronava, the threatened species *Butomus umbellatus* and *Phlomis tuberosa* occur. According to the analysis of animals (Ruzek and Senko 2002; Trnka in Izakovicova et al. 2001) out of 91 vertebrates observed in the environs of the reservoir 70 species are protected by law (57 of them being threatened, 10 very threatened and 3 (*Rana ridibunda*, *Egretta alba*, and *Falco cherrug*) critically threatened). In spite of the fact that the Ronava Reservoir is not the original biotope, its ecosozological value quoted in the Territorial system of ecological stability of Trnava district (Izakovicova et al. 2001) is relatively high, and it is proposed that the area be made a regional biocentre. Agricultural land in the study area is of the best quality and the most fertile in Trnava district, and its production potential is high. In term of mineral resource protection, a part of the study area is monitored as a locality in which natural gas occurs (Izakovicova et al. 2001).

The analytical map shows ecologically important bank growths, agricultural soil of the 1st quality, the occurrence of natural gas, the frequent occurrence of protected animals and the proposed biocentre.

Stress factors.

Natural stress factors. This area suffers from a distinct lack of woody vegetation. The flat open landscape enhances the negative effect of intensive winds, causing wind erosion. Soil dust contaminates the air and is carried to neighbouring areas. In the past, sugar beet and other sensitive crops were often damaged in this way, because the upper layer of the soil contains pesticides and fertilisers. Distinctly lighter areas are observable on the steepest parts of slopes. They are places in which the humus horizon has been partially removed as a result of water erosion. These places are characterised by worse conditions for the

germination and nutrition of plants and consequently, lower fertility compared with their environs.

When the reservoir is filled in springtime with a view to the maximum operational water table being reached, woody growth on some parts of the shore are threatened by undermining, and some areas of arable land are periodically inundated.

Anthropogenic stress factors. Approximately 4 kilometres from the Ronava Reservoir is the works of Johns Manville that is the most important polluter in Trnava district. This plant emits 29 metric tons of solid pollutants annually, 36 metric tons of SO₂, 488 metric tons of NO_x and 48 metric tons of CO. Road traffic and wind erosion also contribute to the air pollution, but their individual shares are not monitored.

The largest source of noise in the study area is intensive car traffic—the D61 motorway with more than 22,000 vehicles a day, and the stretch of the 1st-class road with more than 9,000 vehicles a day (Izakovicova 2001).

Water quality in the Ronava Reservoir is measured 6-times a year. In accordance with the water analyses performed in the years 1999-2002, the Reservoir belongs to the following quality classes:

- physical and chemical indicators—1st or 2nd class (very pure water—pure water)
- microbiological indicators—1st or 2nd class (very pure water—pure water) but at least once a year the occurrence of coliform bacteria or faecal streptococcus abruptly increases (to match criteria of the 4th or 5th classes—very polluted water or extremely polluted water)
- inorganic micropollutants: contents of cadmium, chromium, nickel, lead and zinc are appropriate for the 1st class (very pure water); those of copper and mercury move between the 1st and 2nd classes (very pure water or pure water). Increased contents of aluminium (sufficient for 3rd, 4th or 5th classes, polluted water—extremely polluted water) have been detected repeatedly.

The Reservoir is a part of a hunting ground in which hunting of mallard (*Anas platyrhynchos*) is permitted. Apart from this species, other legally protected species of ducks (*A. clypeata*, *A. crecca*, *A. strepera*, *A. querquedula*) occur here. These birds are threatened by hunting and often fall victim to hunters.

The analytical map shows areas affected by the following stress factors: wind erosion; water erosion; undermining of water basin shores; periodic inundation of arable land; increased noise and air pollution near heavy roads; incidental microbiological pollution of the water reservoir; hunting in an ecologically-valuable area.

LANDSCAPE-ECOLOGICAL SYNTHESIS

Abiocomplex types are the result of partial syntheses, being expressed by the formula

$$At_{1-19} = \{R_{1-8}, I_{1-4}, St_{01-11}, Sx_{1-2}, Ss_{1-3}\}$$

where At is abiocomplex type and there is a combination of abiotic landscape components in brackets, i.e. relief (R), inclination (I), soil type (St), soil texture (Sx) and subsoil (Ss). Abiocomplex types (At₁ – At₁₉) are presented in Table 4.

The main result of this stage is the creation of homogeneous areas described by the formula:

$$LECT_{1-40} = \{At_{1-19}, CLS_{1-22}\}$$

where LECT is a landscape-ecological complex type, At is an abiocomplex type and CLS is an element of contemporary landscape structure. Landscape-ecological complex types are presented on Map 1 and in Table 5.

LANDSCAPE-ECOLOGICAL INTERPRETATION

The overlaying of the map of stress phenomena and that for landscape protection leads to the identification of eight environmental problems:

- agricultural soil of the 1st quality threatened by wind erosion,

Table 4. Partial Landscape-ecological synthesis: Abiocomplex types

At	R	I	St	Sx	Ss
At1	1	1	.08	1	1
At2	1	1	.08	2	1
At3	1	1	.11	2	1
At4	2	1	.01	1	2
At5	2	1	.02	1	2
At6	2	1	.04	1	2
At7	2	1	.05	1	2
At8	3	2	.05	1	2
At9	4	1	.03	1	2
At10	4	2	.02	1	2
At11	4	2	.05	1	2
At12	4	3	.07	1	2
At13	5	2	.03	1	2
At14	5	2	.03	2	2
At15	5	2	.06	1	2
At16	6	1	.10	1	3
At17	7	1	.09	1	3
At18	7	4	.09	1	3
At19	8	1	.11	2	2

Legend: At—Abiocomplex type, R—Relief, I—Inclination, St—Soil type, Sx—Soil texture, Ss—Subsoil.

Note: Code numbers refer to Table 2.

- agricultural soil of the 1st quality threatened by water erosion,
- agricultural soil of the 1st quality affected by air pollution near heavy roads,
- periodically inundated arable land,
- reservoir with incidental microbiological pollution,
- ecologically important bank growth locally threatened by undermining,
- proposed biocentre partially affected by noise near heavy roads,
- the endangering of protected birds by hunting.

The study area was delimited into four categories (Table 6): areas without the above-mentioned problems and areas affected by one, two or three of those considered.

LANDSCAPE-ECOLOGICAL EVALUATION

Measures of SAPARD applicable to the study area.**Measure 1: Investments in agricultural firms.**

Support in this area of plant production is oriented at the adaptation of fruit, vegetable and medicinal and aromatic plants to agri-environmental standards of the EU, promotion of increased quality among agricultural products and reconstruction and modernization of irrigation technologies.

Measure 2: Improvement of processing and marketing of agricultural and fish products. The aim of the measure is to ensure further development of the food-processing industry. The aid in the fish sector is targeted at the modernization of production, storage and transport capacities and technology, new technology and construction, and the reconstruction of wastewater treatment plants. In the vegetable and fruit sector, this measure is targeted at the purchase of sawing and harvesting machines, and the modernization of producing and storing facilities.

Measure 4: Diversifying activities in a rural area. The aim of the measure is to preserve and improve the economic chances and social conditions of the rural population, by providing support to investments which produce and maintain jobs, environmental projects which improve an area and make it more attractive, projects which preserve cultural traditions of a rural population, and those which generate new sources of income.

Supportable investments include the reconstruction and modernisation of holiday and accommodation facilities, the reconstruction of existing agricultural facilities which lost their original purpose, agri-tourism structures, the development of supplementing production, the production of traditional materials and products, the production and sale of local specialities, the construction of agri-tourism facilities, and the development of recreation and relaxation activities.

Measure 7: Land adjustments. The aim of land adaptation is consolidation, separation and other arrangements for owners.

Table 5. Landscape-ecological complex types

LECT ₁ -LECT ₁₀	LECT ₁₁ -LECT ₂₀	LECT ₂₁ -LECT ₃₀	LECT ₃₁ -LECT ₄₀
LECT ₁ = {1,4}	LECT ₁₁ = {4,18}	LECT ₂₁ = {9,17}	LECT ₃₁ = {15,9}
LECT ₂ = {2,1}	LECT ₁₂ = {4,19}	LECT ₂₂ = {10,4}	LECT ₃₂ = {16,6}
LECT ₃ = {2,10}	LECT ₁₃ = {4,21}	LECT ₂₃ = {10,16}	LECT ₃₃ = {16,9}
LECT ₄ = {2,11}	LECT ₁₄ = {4,22}	LECT ₂₄ = {11,9}	LECT ₃₄ = {17,14}
LECT ₅ = {3,12}	LECT ₁₅ = {5,4}	LECT ₂₅ = {11,13}	LECT ₃₅ = {17,15}
LECT ₆ = {4,1}	LECT ₁₆ = {5,7}	LECT ₂₆ = {12,9}	LECT ₃₆ = {18,4}
LECT ₇ = {4,4}	LECT ₁₇ = {6,9}	LECT ₂₇ = {14,2}	LECT ₃₇ = {18,8}
LECT ₈ = {4,5}	LECT ₁₈ = {7,9}	LECT ₂₈ = {14,3}	LECT ₃₈ = {18,20}
LECT ₉ = {4,6}	LECT ₁₉ = {7,13}	LECT ₂₉ = {13,5}	LECT ₃₉ = {19,11}
LECT ₁₀ = {4,16}	LECT ₂₀ = {8,9}	LECT ₃₀ = {13,7}	LECT ₄₀ = {19,12}

Table 6. Environmental problems according to a four-category classification

Category	Number of problems	Problem characteristics	LECTs
A	0		LECTs ₁₋₄ , LECTs ₆₋₁₆ , LECT ₁₉ , ECTs ₂₁₋₂₃ , LECT ₂₅ , LECTs ₂₉₋₃₀ , LECT ₃₂ , LECTs ₃₄₋₃₉
B	1	Agricultural soil of the 1st quality threatened by wind erosion Reservoir with incidental microbiological pollution Ecologically important bank growth locally threatened by undermining Endangering of protected birds by hunting	LECT ₁₇ , LECT ₁₈ , LECT ₃₁ LECT ₃₃ , LECT ₅ , LECT ₄₀ LECT ₂₇ LECT ₂₇ , LECT ₂₈
C	2	Agricultural soil of the 1st quality, threatened by wind and water erosion Agricultural soil of the 1st quality, threatened by wind erosion, and periodically inundated Agricultural soil of the 1st quality, threatened by wind erosion, and affected by air pollution near heavy roads Proposed biocentre with incidental microbiological water pollution, partially affected by noise near heavy roads	LECT ₂₀ , LECT ₂₄ , LECT ₂₆ LECT ₃₁ LECT ₁₈ , LECT ₃₁ LECT ₅ , LECT ₄₀
D	3	Agricultural soil of the 1st quality, threatened by wind and water erosion and affected by air pollution near heavy roads	LECT ₂₄ , LECT ₂₆

The creation of a new optimal spatial arrangement of plots should take into consideration not only the area and quality of plots owned by individual proprietors, but also landscape-ecological stability and anti-erosion measures.

Proposed activities. As the study area is located in a region in which chernozems are dominant and in line with traditional and current land use, the main activity will remain large-scale agricultural production (growing cereals, oil plants and fodder plants) and fish keeping in reservoir. All elements of the non-forest woody vegetation—solitary trees, groups of woody species and line plantations will be preserved, along with permanent grass or herb growth, existing buildings, roads, power lines and

the irrigation system.

In agreement with the selected measures of SAPARD, the following activities were proposed for the study area (Table 7):

Measure 1: *The growing of vegetables and the reconstruction, modernization and extension of the irrigation system.*

Measure 2: *Construction of facilities for the processing and storage of vegetables and fish products (an acclimatized vegetation storage facility, production hall and freezers for fish products).*

Measure 4: *The development of agri-tourism, proposal of a cycle trail, construction of an agri-tourism facility and fishing.*

Measure 7: *The finishing of a hard-surfaced communication link, in order to make plots accessible, and the planting of non-forest woody vegetation.*

Table 7. Activities proposed in the study area

Activity	Measure	Considered landscape characteristics	Possible LECTs
Preservation of the present landscape structural elements	—	Non-forest woody vegetation, buildings , roads, power lines	LECTs ₁₋₁₆ , LECT ₁₉ , LECTs ₂₂₋₂₃ , LECT ₂₅ , LECTs ₂₇₋₃₀ , LECT ₃₂ , LECTs ₃₄₋₄₀
Growing of cereals, oil plants and legumes	—	Arable land quality, relief character	LECT ₁₇ , LECT ₁₈ , LECT ₂₀ , LECT ₂₄ , LECT ₃₁ , LECT ₃₃
Growing of fodder plants and permanent cultures	—	All arable land	LECT ₁₇ , LECT ₁₈ , LECT ₂₀ , LECT ₂₄ , LECT ₂₆ , LECT ₃₁ , LECT ₃₃
Growing of vegetables	1	Arable land quality, relief character, air pollution-affected areas, irrigation	LECT ₁₇ and LECT ₁₈ (near LECT ₁₂ , B category only)
Reconstruction and modernization of irrigation system	1	Existence of irrigation system	LECT ₁₂
Broadening of irrigation system (mobile irrigation system)	1	Vicinity of water source	LECT ₁₇ , LECT ₁₈ , LECT ₂₀ , LECT ₂₄ , LECT ₃₁ , LECT ₃₃ (near LECT ₅ , LECT ₄₀)
Construction of processing facilities	2	Relief character, power lines, hard access road	LECT ₁₇ , LECT ₁₈ , LECT ₃₃ (near LECT ₁₉ and LECT ₁₀)
Construction of agri-tourist facility	4	Noise-stricken areas, air-pollution affected areas, relief character, electric lines, firm access road	LECT ₁₇ , LECT ₁₈ , LECT ₃₃ (near LECT ₁₉ and LECT ₁₀ , B category only)
Bicycle tourism	4	Quality of roads	LECT ₁₀ , LECT ₂₃
Fishing, fish keeping	1 and 4	Reservoir	LECT ₅ , LECT ₄₀
Finishing of hard-surfaced road	7	Existence of dirt road	LECT ₂₁
Planting of non-forest woody vegetation		Existence of dispersed woody vegetation, soil quality, relief character	LECT ₁₇ , LECT ₁₈ , LECT ₂₀ , LECT ₂₄ , LECT ₂₆ , LECT ₃₁ , LECT ₃₃ (close to LECT ₂ , LECT ₆ , LECT ₈ , LECT ₂₉ , and LECT ₃₄ , LECT ₃₅ , LECT ₁₀ , LECT ₂₃)

The evaluation process is presented in Table 8.

LANDSCAPE-ECOLOGICAL PROPOSALS

Proposal for ecologically-optimal land use.

Optimum conditions for vegetable-growing exist on the right shore of the reservoir, on the flat ground with good quality and deep soils, and a possibility of irrigation, at a sufficient distance from frequented roads. The finishing of the irrigation system in an area without water lines is suitable.

Most other arable land is suitable for growing other agricultural crops, while it is proposed that the present crop rotation system targeted at the alternation of cereals and oil plants should include legume- or permanent-crop growing. Permanent fodder plants, permanent grassland, or permanent crops are proposed for slopes with an erosional form of chernozem.

The plain in the neighbourhood of the farm next to the dike is suitable for the construction of storage and processing facilities for vegetables. This locality is comfortably accessible via the hard-surfaced road, there is the possibility of a direct connection to the power line, the relief is relatively flat and after the construction of the waste water treatment plant, this can be connected with the outlet channel of the reservoir. The locality is suitable for the same reasons for the construction of other storage or processing facilities (for example in fish processing and freezing plants).

Due to the flat relief, the area is suitable for the development of cycling tourism. The cycling trail connecting two existing holiday centres in the vicinity of the study area (Kamenny Mlyn in the town of Trnava and Sporthotel Gidra in the village of Pac) can pass through the area.

In the case of the construction of the seasonal holiday centre, the most suitable locality on this cycling route is the area of the former farm, some buildings of which were pulled down. This area is not included in the agricultural land reserve. It lies in a calm environment in the vicinity of the reservoir, where there are varied services

available (fishing, water sports). The old and not operational water tower, all that is left of the former farm, can be adapted to serve as a viewing tower with a view of the reservoir for animal observation (field animals, herons, falcons, etc.). It would be appropriate to situate there some resting places for cyclists (a wooden table, a bench, a rubbish bin) and to chose and delimit space for fireplaces.

Planting of woody species is proposed, especially along the roads. The following woody species are indicated (Altmanova 1987): *Tilia cordata*, *Quercus robur*, *Quercus cerris*, *Ulmus minor*, *Fraxinus ornus*, *Acer campestre*, *Sorbus aucuparia*, *Carpinus betulus*, *Ligustrum vulgare*, *Viburnum lantana*, *Cornus mas*, *Lonicera xylosteum*, *Corylus avellana*, *Crataegus monogyna*, *Crataegus laevigata*, *Rosa canina*, *Rhamnus cathartica*, *Prunus spinosa*, *Prunus mahaleb*, *Malus silvestris* and *Sorbus torminalis*. The same woody species are cited as being suitable for planting in bank vegetation of the Ronava River and the Ronava Reservoir.

Measures ensuring ecological stability and biodiversity.

The central part of the territory consists of the proposed biocentre of the Regional Territorial System of Ecological Stability, the drawback of which is the narrow ecotonal belt isolated within the landscape (Izakovicova et al. 2001). The issue of biocorridors at the level of the local territorial systems of ecological stability should be resolved finally.

The arable fields are too large. From the point of view of ecological stability, it is more appropriate that several crops be grown on smaller fields, accompanied by introduced perennial cultures (fodder plants, permanent grasslands, tree lines). Management in line with agri-environmental schemes applied in the Community countries (European Commission 1999, Morris 2004, Gillmor 2003, Kristensen 2003) may solve the problem.

Following the construction of the reservoir and the consequent ensuring of optimal ecological conditions, the hydrophilous

Table 8. Landscape-ecological evaluation

Activity LECT	Preservation	Agricultural utilisation				Infrastructural investment						Landscape protection	
	Preservation of CLS elements	Growing of vegetables	Growing of cereals, oil plants and legumes	Growing of permanent and perennial cultures	Fishing, fish-keeping	Modernisation of irrigation system	Expansion of irrigation system	Construction of processing facilities	Construction of agro-tourist facility	Cycling	Finishing of firm road	Planting of woody vegetation	Proposal of territorial protection
LECT1	1	x	x	x	x	x	x	x	x	x	x	1	x
LECT2	1	x	x	x	x	x	x	x	x	x	x	1	x
LECT3	1	x	x	x	x	x	x	1	x	x	x	1	1
LECT4	1	x	x	x	x	x	x	1	x	x	x	1	x
LECT5	1	x	x	x	1	x	1	x	x	x	x	x	1
LECT6	1	x	x	x	x	x	x	x	x	x	x	1	x
LECT7	1	x	x	x	x	x	x	x	x	x	x	1	x
LECT8	1	x	x	x	x	x	x	x	x	x	x	1	x
LECT9	1	x	x	x	x	x	x	x	x	x	x	x	x
LECT10	1	x	x	x	x	x	x	1	1	1	x	1	x
LECT11	1	x	x	x	x	x	x	x	x	x	x	x	x
LECT12	x	x	x	x	x	1	x	x	x	x	x	x	x
LECT13	1	x	x	x	x	x	x	x	x	x	x	x	x
LECT14	1	x	x	x	x	x	x	x	x	x	x	x	x
LECT15	1	x	x	x	x	x	x	x	x	x	x	1	x
LECT16	1	x	x	x	x	x	x	x	x	x	x	x	1
LECT17	x	1	1	1	x	x	x	1	1	x	x	0	x
LECT18	x	1	1	1	x	x	1	1	1	x	x	0	x
LECT19	1	x	x	x	x	x	x	x	x	x	x	x	x
LECT20	x	1	1	1	x	x	1	2	2	x	x	2	x
LECT21	x	x	x	x	x	x	x	x	x	2	1	x	x
LECT22	1	x	x	x	x	x	x	x	x	x	x	1	x
LECT23	1	x	x	x	x	x	x	1	1	1	x	1	x
LECT24	x	2	1	1	x	x	1	2	2	x	x	2	x
LECT25	1	x	x	x	x	x	x	x	x	x	x	x	x
LECT26	x	0	2	1	x	x	x	0	0	x	x	1	x
LECT27	1	x	x	x	x	x	x	x	x	x	x	1	1
LECT28	1	x	x	x	x	x	x	x	x	x	x	1	1
LECT29	1	x	x	x	x	x	x	x	x	x	x	1	x
LECT30	1	x	x	x	x	x	x	x	x	x	x	x	1
LECT31	x	1	1	1	x	x	1	1	1	x	x	0	x
LECT32	1	x	x	x	x	x	x	x	x	x	x	x	x
LECT33	x	1	1	1	x	x	1	1	1	x	x	0	x
LECT34	1	x	x	x	x	x	x	x	x	x	x	x	x
LECT35	1	x	x	x	x	x	x	x	x	x	x	x	x
LECT36	1	x	x	x	x	x	x	x	x	x	x	1	x
LECT37	1	x	x	x	x	x	x	x	x	x	x	x	x
LECT38	1	x	x	x	x	x	x	x	x	x	x	x	x
LECT39	1	x	x	x	x	x	x	x	x	x	x	1	x
LECT40	1	x	x	x	1	x	1	x	x	x	x	x	1

Legend: 1—suitable, 2—less suitable, 0—unsuitable, x—irrelevant.

biocenoses on its shores revived and widened. The natural succession of shore vegetation determines the composition of the local fauna, particularly ornithocenoses. In the coming years, it is possible to expect a widening of the vegetation, especially that of *Phragmites australis*, that may lead to the formation of new nidobiotopes of other waterfowl species and other groups of animals. Optimal conditions for nesting are on the right shore. There is no access road and disturbance is minimal. It is important to limit oscillation of the water table in the nesting period (April–July), in order to prevent flooding of nests of those species, that build their nests on the bottom or littoral vegetation of the drained reservoir.

Measures palliating the impact of stress factors. As vegetation cover minimizes the risk of soil erosion it is proposed to extend the area in which 'green' manuring (with white mustard and legumes) is used. Its application is especially desirable on plots not sown with winter crops. The reservoir causes problems with local flooding of arable land, above all in springtime. A possible solution is to cover the surface with another layer of quality earth. This method was used successfully in several places in the area (areas with a recultivated anthrozem).

It is necessary to check on water quality in the reservoir regularly, in order that water can be used in irrigation. In spite of the fact that most of the parameters comply with the criteria for pure or very pure water, critical values for microbiological pollution were repeatedly found here. The administrator of the reservoir should seek the causes and ensure a remedy.

To eliminate the impact of noise and exhaust fumes from the motorway, it is necessary for the plantation of woody species along the motorway to be supplemented and widened.

With regard to the abundant occurrence of protected birds in the environs of the reservoir, the hunting of wild ducks should be prohibited and the whole biocentre and its environs taken out of the hunting areas.

FINAL REMARKS

The reforms of Common Agricultural Policy have had and will continue to have a positive impact on the rural environment. This can, however, be developed further by ensuring that a greater share of the funding goes to measures that are environmentally friendly (European Commission 2001).

SAPARD represents an economic tool that helps approximate the level of agriculture in the new member states to that of the advanced European countries. Measures under SAPARD are almost identical to those which the European Agricultural Guidance and Guarantee Fund (EAGGF) supports under the Sectoral Operational Programme for Agriculture and Rural Development following the accession of Slovakia to the European Union.

Our results suggest that, in preparing a landscape-ecological plan, it is possible to take into account defined priorities, and to propose land use that is not only ecologically acceptable and desirable for society, but also financially sustainable. The presented Landscape-Ecological plan represents a way in which to include measures resulting from Common Agricultural Policy (CAP) reform into landscape utilization proposals (suitable areas for organic farming, afforestation, realization of concrete agri-environmental schemes, etc.) The linkage between the individual projects in a region is also an advantage for farmers where the approval process is concerned.

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