Functional-geographical approach 2

USER REQUIREMENTS

Planning for river rehabilitation will generally aim at safe, multifunctional and ecologically sustainable rivers. In the preceding chapter it was argued that the planning process should be accompanied by research on the functioning of rivers to achieve these goals. Research yields relevant information for making the appropriate choices in the planning process. Peck (1998) mentioned various reasons for collecting this information: (1) to gain sufficient knowledge to make planning recommendations and decisions, (2) to test the outcome of models and hypotheses during the planning process, (3) to create baseline data for monitoring, (4) to indicate information gaps or areas that require specific research, and (5) to increase general understanding of river functioning. In reality, however, emphasis is on the first reason.

From a water management perspective, scientific information supporting the decision-making process in rehabilitation planning should meet the following requirements (Rademakers and Wolfert, 1994; Wolfert, 1996): (1) information must cover the entire plan area to enable comparison of its constituent parts, (2) the information should relate to results of research from other disciplines as part of an integrated approach encompassing the various river functions, (3) the type of information should be related to the measures proposed by water managers to enable the impacts of these measures to be assessed, and (4) information must be gathered efficiently, since the planning process generally is relatively short and research budgets are limited. These requirements define the type of research associated with the river rehabilitation planning process.

In this chapter an approach towards efficient river rehabilitation studies is elaborated, building on (1) methods of land evaluation applied successfully in spatial planning processes (e.g. Verstappen, 1983; Zonneveld, 1995) and (2) the hierarchical framework for habitat classification (Frissell et al., 1986) and the fluvial hydrosystem concept (Petts and Amoros, 1996) developed for studying river systems in an applied context.

LAND RESOURCE INVENTORY

Information covering an entire plan area is usually gathered in a resource inventory, with which most spatial planning processes start. Land resource inventories are adequate, because the planner is concerned with the designation of areas. Such an approach has a long tradition in rural land use planning. In the Australian land-systems survey, applied world wide in the 1950s and 1960s, the inventory was based on the

recognition of land systems which contain a recurring pattern of various related aspects, such as geomorphology, soils and vegetation different from those of adjacent areas (see Verstappen, 1983; Cooke and Doornkamp, 1990). Similar methods are still being used in land resources surveys. With the emergence of landscape ecology as a science in the 1970s, emphasis shifted from the description of patterns to the study of functional topological (i.e. vertical) and chorological (i.e. horizontal) process relationships between the abiotic and biotic components (Leser, 1976). These inventories yield geographical data on patterns, processes and changes in space and time, which are usually stored and presented in maps, and more recently in Geographical Information Systems.

Land resource inventories require a classification system in which information of the land system studied is presented in a systematic way (Lotspeich and Platts, 1982). According to Cowardin and Golet (1995), the major objectives of a classification system are to: (1) describe units that have certain homogeneous natural attributes, (2) arrange these units in a system that will aid decisions about resource management, (3) identify classification units for inventory and mapping, and (4) provide uniformity in concepts and terminology. In physical land evaluation, land units are classified. Land units are defined as ‘a tract of land that is ecologically relatively homogeneous at the scale level concerned’ (Zonneveld, 1995). ‘Land’ may also encompass all water, lakes or rivers flowing from or across these lands (Lotspeich and Platts, 1982).

To approach naturally homogenous land units, two different methods can be recognised (Conquest et al., 1994, Zonneveld, 1995). Ideally, data on characteristics of land units are subjected to statistical techniques, such as cluster analysis and principle components analysis, to derive a posteriori patterns and indicate relationships. This bottom-up methodology is frequently applied in vegetation science and aquatic ecology, using much data on plants and invertebrates and their sites and habitats. An efficient alternative is to search for spatial patterns in land unit characteristics of the area studied, and a priori classify these land units based on logical rules. This top-down methodology is well known from physical land evaluation studies and landscape ecological research. It requires far less data, but can only be applied successfully when sufficient knowledge of the ecosystem functioning is available. Knowledge of river ecosystems is assumed to be sufficient to allow a top-down methodology to be used.

LANDFORMS AND GEOMORPHOLOGICAL PROCESSES

To provide a framework in which results from various disciplines can be integrated, the topological interactions between the abiotic and biotic components of land units are viewed in most land evaluation systems as a simple model of hierarchical influence (Fig. 2.1). A chain of asymmetric relationships is distinguished, from the subsystem climate to the subsystems geology, geomorphology, hydrology, soils, flora and fauna (e.g. Bakker et al., 1981; Klijn, 1995). In this sequence, fauna species are largely dependent on vegetation, vegetation on soils, soils on hydrology, and so on. At a regional level, geomorphology is considered to be the central and most meaningful abiotic system, as

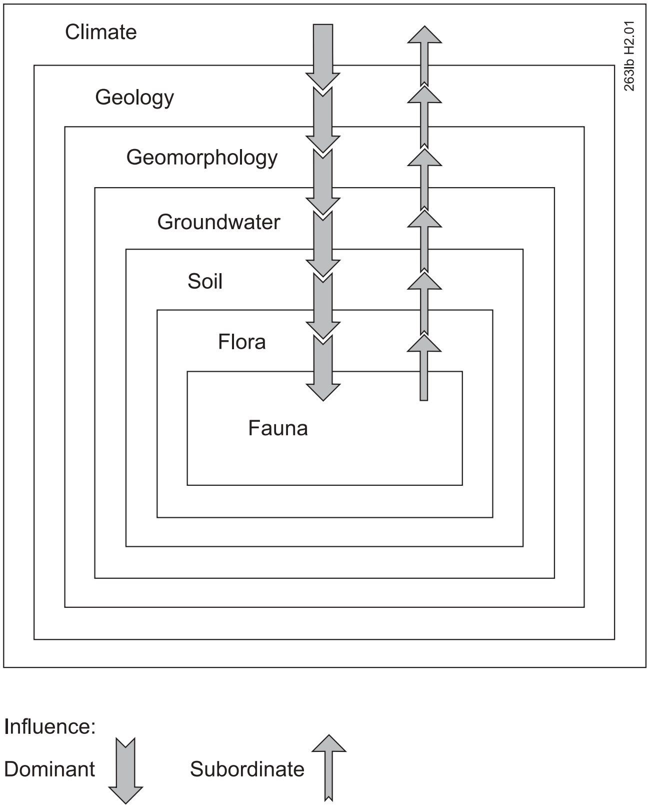

Fig. 2.1.
A hierarchical model of topological ecosystem relationships (from: Klijn, 1995)

it is closely correlated with geology and determines hydrological processes and subsequent soil developments. Landforms thus play a prominent part in the land inventory classification (Godfrey, 1977; Van Zuidam and Van Zuidam-Cancelado, 1985), especially as they are easily recognisable features which may be mapped relatively quickly, either in the field or using remote sensing techniques.

Landforms are central to most land inventory systems, which is clearly justified where the fluvial system is concerned. Its morphodynamics are responsible for a young topography that is generally more prominent than that of adjacent areas. The biological patterns of fluvial systems are assumed to be largely adjusted to and controlled by the physical patterns and processes. Consequently, most integrated classification systems for rivers are based upon the physical patterns (Lotspeich and Platts, 1982; Frissell et al., 1986, Kern, 1994). The influence of geomorphology on flora and fauna in river systems is related to morphodynamics and hydrodynamics (Knaapen and Rademakers, 1990). Morphodynamics include the mechanical and physical influences of flowing water on substrate, vegetation and animals, the most dominant processes being erosion

and sedimentation. Morphodynamics are reflected in the geomorphological structure of the channel bed and floodplain. Hydrodynamics relate to the physiological and hydrological influence of water on site, vegetation and animals. It includes water depth, flooding duration and fluctuations of the groundwater level. These variables clearly depend on the channel bed and floodplain relief. Information on genesis and relief of landforms is usually provided by geomorphological maps, which are therefore valuable as tools for integrated river rehabilitation planning.

FUNCTIONAL HIERARCHIES

For efficient collection and dissemination of information for application by river managers, research must be attuned to the mission, legal powers and land under the responsibility of the organisations involved in planning and water management. Organisations may operate at a transboundary (e.g. European Union), internal (e.g. country, state), local (e.g. water board, municipality) or landowner level (e.g. nature reserve, farm). Each of these require their own level of information (Delft Hydraulics, 1992; Klijn, 1995). One way to define the appropriate scale is to match the level in the administrative or decision hierarchy with a relevant perspective of the organisation in the river system. The use of river system hierarchies in applied river research has been advocated by Frissell et al. (1986), Kern (1994), Amoros et al., (1987), Petts and Amoros (1996) and Newbury (1996), and explored successfully in various underlying disciplines, such as hydroclimatology (Hirschboeck, 1988), sedimentology (Allen, 1983; Miall, 1985; Weber, 1986) and geomorphology (Jackson, 1975; Schumm, 1988). However, the hierarchies proposed differ in the levels distinguished, in the weights given to the abiotical and biotical aspects and in terminology.

An interesting point in this context is that the smaller phenomena in river systems are often used to describe the difference between the larger ones. For instance, various types of bars have characteristic patterns of ripples and dunes, and different fluvial styles are characterised by specific bedform assemblages. Moreover, the larger these phenomena are, the longer they exist. Thus, Jackson (1975) introduced a unifying, hierarchical model of macro, meso and micro bedforms, mainly based on bedform size, time-span of existence and superposition. Similarly, a process-functional hierarchy is proposed here for use in river rehabilitation studies, of which the levels can be detected in all types of river systems and together form a consistent nested hierarchy. These levels are: (1) the river domain, composed of a characteristic set of river reaches, (2) the river reach domain, characterised by recurring patterns of macro bedforms, and (3) the river macroform domain, showing superimposed small-scale bedform patterns (Fig. 2.2). A comparison of nomenclature is given in Table 2.1.

The river domain comprises all surface waters within the drainage basin. Theoretically, in each river system a zone of erosion, a zone of transfer, and a zone of deposition may be distinguished (Schumm, 1977; 1988), but generally a much larger variety of river reaches can be observed. River reaches are often characterised by certain species of invertebrates, fish and vegetation (Mosley, 1987; Naiman et al., 1992; Large

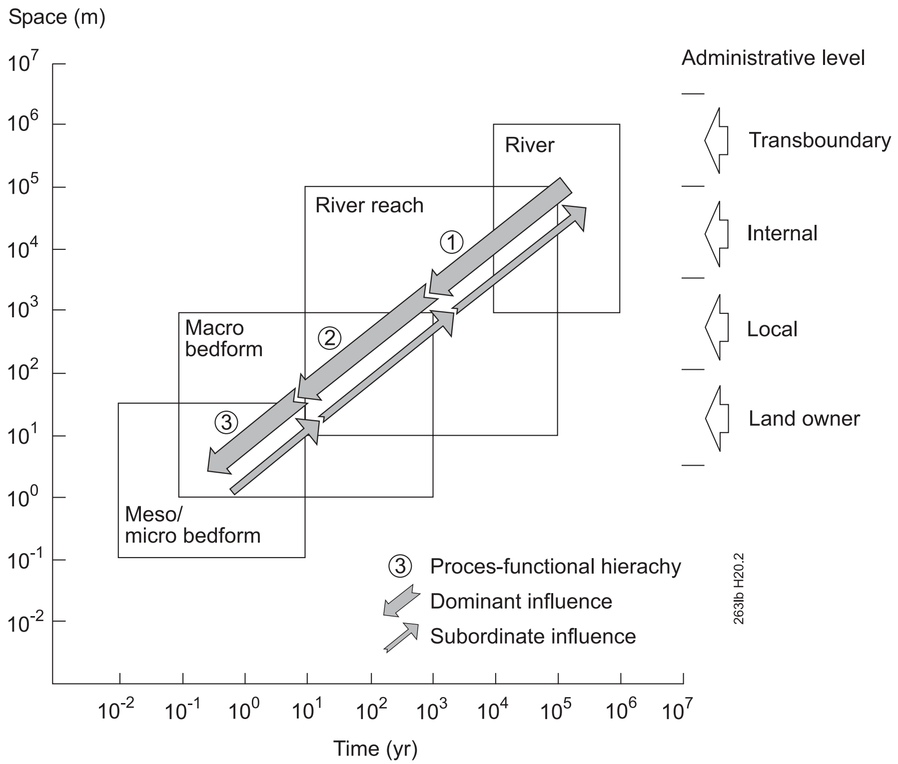

Fig. 2.2.
A model of process-functional hierarchies in river systems compared to the levels of the administrative hierarchy. Envelopes of spatio-temporal domains are derived from Frissell et al. (1986), Kern (1994) and Petts and Amoros (1996)

et al., 1996; Roux and Copp, 1996), while reach discontinuities were observed to result in distinct changes in aquatic species assemblages and in a lower floodplain biodiversity (Hughes et al., 1994; Statzner and Higler, 1986; Stanford et al., 1996). Examples of macro bedforms are pools and riffles in streams, and bars, sloughs and natural levees in large alluvial rivers. Many classifications of typical macro bedform assemblages have been developed (e.g. Miall, 1985; Nanson and Croke, 1992; Rosgen, 1994; Downs, 1995; National Rivers Authority, 1996.). Macroforms are the basic units in river ecological classifications, for example the functional unit of Amoros et al. (1987) and the river ecotope of Rademakers and Wolfert (1994). The small-scale bedforms encompass features such as dunes and ripples (Reineck and Singh, 1980) but also minor channels and bars. The variability of small-scale bedforms is related to the behaviour and life history adaptation of stream organisms (Frissell et al., 1986).

In hierarchical models of river systems, the various independent variables are assigned to specific levels in the hierarchy, because what appear to be the most controlling or constraining variables often changes according to the time-frame in

Table 2.1.
Comparison of nomenclature used to indicate the spatio-temporal domains in fluvial systems

REFERENCE	DISCIPLINE	SPATIO-TEMPORAL DOMAIN			
		River	**River reach**	**Macro bedform**	**Meso and micro bedform**
Miall, 1985	Fluvial sedimentology	Depositional system	Fluvial style	Architectural element	Lithofacies
Frissell et al., 1986	River ecology	Stream system	Segment system; reach system	Pool/riffle system	Microhabitat system
Weber, 1986	Fluvial sedimentology	Basin scale	Reservoir scale	Genetic unit scale	Grain size scale
Amoros et al., 1987	River ecology	Drainage basin	Functional sector	Functional unit	Functional describer
Schumm, 1988	Fluvial geomorphology	River system	River reach	Meander; sand bar	Bedforms (ripples and dunes)
Kern, 1994	River ecology	Gewässersystem	Gewässerabschnitt / Talboden; Gewässerstrecke / Überschwemmungsaue	Bettstructure / Auenhabitate	Microhabitate
Petts and Amoros, 1996	River ecology	Drainage basin	Functional sector	Functional unit; functional set	Mesohabitat
Newbury, 1996	Stream hydraulics	Catchment scale	Stream reach scale	Habitat scale	Microhabitat scale

which the system is viewed (Frissell et al., 1986). This allows a selection to be made of the variables most relevant to the organisations involved in rehabilitation planning. Independent and dependent variables often mentioned in relation to the three levels in the process-functional hierarchy are listed in Table 2.2. In Fig. 2.2, these levels are compared to the areas covered by the various administrative levels. Assuming that the internal and local administrative levels are the most relevant in spatial planning, comparison shows that some of the independent variables cannot be influenced since their spatial domain far exceeds that of the area of jurisdiction of the water manager. Besides, it appears that the variables at the river reach–macro bedform level are right in the middle of the sphere of influence of rehabilitation planners. Thus it can be concluded that the domain of the river reach characterised by recurring patterns of macro bedforms is especially suited for use in studies for river rehabilitation purposes. River reaches and their characteristics are the result of large discharge events and require many decades to develop. Historical studies, therefore, are considered extremely relevant to rehabilitation research.

CONCLUSIONS

Starting from the hierarchical framework for habitat classification (Frissell et al., 1986)

Table 2.2.
Independent and dependent variables often mentioned in relation to the three levels in the process-functional hierarchy

LEVEL	INDEPENDENT VARIABLES	DEPENDENT VARIABLES
River with river reaches	Climate Tectonics Geological setting Basin relief Land cover	Valley type Longitudinal profile Channel pattern
River reach with macro bedforms	Discharge of water Discharge of sediment Valley slope Bank material Bank vegetation	Channel dimensions Bedform types and configuration Architectural elements
Macroforms with meso and micro bedforms	Flow velocity Stream power Sediment grain size Aquatic and bank vegetation	Bedform dimensions Bedform types and configuration Lithofacies

and the fluvial hydrosystem concept (Petts and Amoros, 1996) some user requirements typical of the spatial planning process were used to define research procedures for river rehabilitation purposes. (1) Compared with previous work by the authors mentioned, the four-dimensional approach is expanded through the addition of land resource inventories using a top-down classification method. (2) Like both concepts, information on physical patterns and processes is considered to be the most meaningful, but more emphasis is put on the use of geomorphological maps (3) The proposed approach differs from the hierarchies of Frissell et al. (1986) and Petts and Amoros (1996) in the use of a process-functional hierarchy, in which the central domain of river reaches characterised by recurring patterns of macro bedforms is considered the most appropriate to organisations involved in river rehabilitation planning.

REFERENCES

Allen, J.R.L., 1983. Studies in fluviatile sedimentation: bar-complexes and sandstone sheets (low-sinuosity braided streams) in the Brownstones (L. Devonian), Welsh Borders. Sedimentary Geology 33, 237–293.

Amoros, C., Roux, A.L., Reygrobellet, J.L., Bravard, J.P., Pautou, G., 1987. A method for applied ecological studies of fluvial hydrosystems. Regulated Rivers 1, 17–36.

Bakker, T.W.M., Klijn, J.A., Van Zadelhoff, F.J., 1981. Nederlandse kustduinen: landschapsecologie. Centrum voor landbouwpublicaties en landbouwdocumentatie, Wageningen.

Conquest, L.L., Ralph, S.C., Naiman, R.J., 1994. Implementation of large-scale stream monitoring efforts: sampling design and data analysis issues. In: Loeb, S.L., Specie, A., (Eds.), Biological Monitoring of Aquatic Systems. Lewis Publishers, Boca Raton, pp. 69–90.

Cooke, R.U., Doornkamp, J.C., 1990. Geomorphology in Environmental Management: a New Introduction. Clarendon Press, Oxford. Second Edition.

Cowardin, L.M., Golet, F.C., 1995. US Fish and Wildlife Service 1979 wetland classification: a review. Vegetatio 118, 139–152.
Delft Hydraulics, 1992. Coasts, a matter of scale. Hydro Delft 80, 2–3.
Downs, P.W., 1995. River channel classification for channel management purposes. In: Gurnell, A., Petts G. (Eds.), Changing River Channels. John Wiley & Sons, Chichester, pp. 345–365.
Frissell, C.A., Liss, W.J., Warren, C.E., Hurley, M.D., 1986. A hierarchical framework for stream habitat classification: viewing streams in a watershed context. Environmental Management 10, 199–214.
Godfrey, A.E., 1977. A physiographic approach to land use planning. Environmental Geology 2, 43–50.
Hirschboeck, K.K., 1988. Flood hydroclimatology. In: Baker, V.R., Kochel, R.C., Patton, P.C. (Eds.), Flood Geomorphology. John Wiley & Sons, New York, pp. 27–49.
Hughes, R.M., Heiskary, S.A., Matthews, W.J., Yoder, C.O., 1994. Use of ecoregions in biological monitoring. In: Loeb, S.L., Specie, A. (Eds.), Biological Monitoring of Aquatic Systems. Lewis Publishers, Boca Raton, pp. 125–151.
Jackson, R.G. II, 1975. Hierarchical attributes and a unifying model of bed forms composed of cohesionless material and produced by shearing flow. Geological Society of America Bulletin 86, 1523–1533.
Kern, K., 1994. Grundlagen naturnaher Gewässergestaltung: Geomorphologische Entwicklung von Fließgewässern. Springer-Verlag, Berlin.
Klijn, J.A., 1995. Hierarchical concepts in landscape ecology and its underlying disciplines. Report 100, DLO Winand Staring Centre, Wageningen.
Knaapen, J.P., Rademakers, J.G.M., 1990. Rivierdynamiek en vegetatieontwikkeling. Rapport 82, Staring Centrum, Wageningen.
Large, A.R.G., Pautou, G. Amoros, C., 1996. Primary production and primary producers. In: Petts, G.E., Amoros, C. (Eds.), Fluvial Hydrosystems. Chapman & Hall, London, pp. 117–136.
Leser, H., 1976. Landschaftsökologie. Uni-Taschenbücher 521, Eugen Ulmer, Stuttgart.
Lotspeich, F.B., Platts, W.S., 1982. An integrated land-aquatic classification system. North American Journal of Fisheries Management 2, 138–149.
Miall, A.D., 1985. Architectural-element analysis: a new method of facies analysis applied to fluvial deposits. Earth-Science Reviews 22, 261–308.
Mosley, M.P., 1987. The classification and characterization of rivers. In: Richards K. (Ed.), River Channels: environment and process. Basil Blackwell, Oxford, pp. 295–320.
Naiman, R.J., Lonzarich, D.G., Beechie, T.J., Ralph, S.C., 1992. General principles of classification and the assessment of conservation potential in rivers. In: Boon, P.J., Calow, P., Petts, G.E. (Eds.), River Conservation and Management. John Wiley & Sons, Chichester, pp. 93–123.
Nanson, G.C., Croke, J.C., 1992. A genetic classification of floodplains. Geomorphology 4, 459–486.
National Rivers Authority, 1996. River habitats in England and Wales: a national overview. River Habitat Survey Report 1, National Rivers Authority, Bristol.
Newbury, R.W., 1996. Dynamics of flow. In: Hauer, F.R., Lamberti, G.A. (Eds.), Methods in Stream Ecology. Academic Press, San Diego, pp. 75–92.
Peck, S. 1998. Planning for Biodiversity: Issues and Examples. Island Press, Washington D.C.
Petts, G.E., Amoros, C. (Eds.), 1996. Fluvial Hydrosystems. Chapman & Hall, London.
Rademakers, J.G.M., Wolfert, H.P., 1994. Het rivier-ecotopen-stelsel: een indeling van ecologisch relevante ruimtelijke eenheden ten behoeve van ontwerp- en beleidsstudies in het buitendijkse rivierengebied. Publicaties en rapporten van het project 'Ecologisch Herstel Rijn en Maas' 61-1994, Rijksinstituut voor Integraal Zoetwaterbeheer en Afvalwaterbehandeling, Lelystad.
Reineck, H.-E., Singh, I.B., 1980. Depositional Sedimentary Environments: With Reference to Terrigeneous Clastics. Springer-Verlag, Berlin. Second, revised and updated edition.
Rosgen, D.L., 1994. A classification of natural rivers. Catena 22, 169–199.
Roux, A.L., Copp G.H., 1996. Fish populations in rivers. In: Petts, G.E., Amoros, C. (Eds.), Fluvial

Hydrosystems. Chapman & Hall, London, pp. 167–183.
Schumm, S.A., 1977. The Fluvial System. John Wiley & Sons, New York.
Schumm, S.A., 1988. Variability of the fluvial system in space and time. In: Rosswall, T., Woodmansee, R.G., Risser, P.G. (Eds.), Scales and Global Change. John Wiley & Sons, Chichester, pp. 225–250.
Stanford, J.A., Ward, J.V., Liss, W.J., Frissell, C.A., Williams, R.N., Lichatowich, J.A., Coutant, C.C., 1996. A general protocol for restoration of regulated rivers. Regulated Rivers: Research & Management 12, 391–413.
Statzner, B., Higler, B., 1986. Stream hydraulics as a major determinant of benthic invertebrate zonation patterns. Freshwater Biology 16, 127–139.
Van Zuidam, R.A., Van Zuidam-Cancelado, F.I., 1985. Aerial Photo-Interpretation in Terrain Analysis and Geomorphologic Mapping. Smits Publishers, The Hague.
Verstappen, H.Th., 1983. Applied Geomorphology: Geomorphological Surveys for Environmental Development. Elsevier, Amsterdam.
Weber, K.J., 1986. How heterogeneity affects oil recovery. In: Lake, L.W., Carroll, H.B. Jr. (Eds.), Reservoir Characterization. Academic Press, New York, pp. 487–544.
Wolfert, H.P., 1996. Rijkswateren-Ecotopen-Stelsels: uitgangspunten en plan van aanpak. Nota 96.050, Rijksinstituut voor Integraal Zoetwaterbeheer en Afvalwaterbehandeling, Lelystad.
Zonneveld, I.S., 1995. Land Ecology: an Introduction to Landscape Ecology as a Base for Land Evaluation, Land Management and Conservation. SPB Academic Publishers, Amsterdam.