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Analysis of river morphological and environmental changes with the integration of historical data and image processing

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Abstract Changes in river morphology and environmental parameters have been studied for the last two decades in the 92 km^2 catchment of the Dragonja River in the submediterranean part of Slovenia. The erosion processes were most intensive 25 years ago due to poor vegetation cover (only 30% of the area was covered by tree/bush vegetation) and locally intensive erosion of material from steep and narrow valleys. Intensive sediment transport dynamics sustained large gravel bar areas along the river. Erosion prevention measures, natural re-vegetation and the reduced frequency and duration of high water flows have reduced sediment supply, sediment transport dynamics and bank erosion. Land use analysis, field inspections and analysis of the river morphology show that the erosion has been reduced by more than half. Average active channel bottom width in 1994 was 60% smaller than that in 1975. In the river section where the sediment transport was most intensive, half of the gravel bar areas are overgrown and stabilized by vegetation. Many parallel channels are hardly active. The ecological parameters of the river and its valley have changed a great deal.

INTRODUCTION

Decision makers need systematic identification of possible environmental impacts, as well as an analysis of their magnitude and probability. The combination of the two approaches: environmental impact assessment and risk assessment, are applied primarily to new project proposals but many of the most serious hazards arise from existing situations and cumulative patterns. There is still a lack of unified assessment methods for existing complexes of hazards for human health and ecological systems. (Andrews, 1995). The dynamic nature of ecological systems (ecosystems) and the degree to which humans have modified their structure and function are not taken into account, if not forgotten, when we assess the impacts of new projects or when we consider management rules for natural resources. Today's management of natural resources should emphasize sustainable ecosystems rather than sustainable yield. This new paradigm, termed ecosystem management, focuses on management of whole systems for a variety of purposes, rather than simply focusing on commodity production for a single resource (Vogt *et al.*, 1996). Therefore, ecosystem management needs to go beyond using our human values to identify what is or is not desirable in an ecosystem (Stanley, 1995). The ecosystem approach needs to be based on biological and ecological information that also incorporates uncertainty. Knowing the current state of a system is a fundamental starting point for water management.

The ignorance or neglecting of fundamental hydrological principles may result in negative effects. The most persistent misuse is that relating to land use. Humans do not seem to learn from experience that changing upstream conditions may adversely affect the downstream water regime (Harremoës, 1995). Deforestation and the construction of dams are the most striking examples. Afforestation and erosion prevention have not been considered important so far, in spite of the fact that they also change the water regime and stream morphology. Therefore, an analysis of the morphological and hydrological characteristics of a catchment is crucial for evaluation of its environmental state and for prediction of the impacts that management and development plans may have, not only on the river, but also on the environment.

The ecological conditions of stream corridors strongly depend on the river morphological processes and hydrological conditions, as well as the catchment geology, topography, climatology, vegetation cover, land use practices and human interventions. Hydrological and morphological phenomena have been studied on the Dragonja River to learn about the natural dynamics of the processes. The natural value of the river and its valley is considered high, since there have been hardly any large technical interventions in the main channel in the past. The lowest section of the river channel has been regulated, whereas the upper and the middle part of the river have retained their natural flow. Therefore plans exist to designate the valley as a landscape park. On the other hand, an irrigation project involving damming the upper river is included in the national development plan. In the coming conflict over these differing plans, evaluation of the natural phenomena and possible impacts due to river damming and water re-distribution are even more important.

The aim of this study is to evaluate the current state of the water regime, on which suitable water management of the Dragonja River will be introduced. It is based on watershed ecosystem study methods, as developed by Swift *et al.* (1988) (land use, macro scale vegetation types), and coupled with stand level studies of ecosystem structural and functional changes at a smaller scale (Vogt *et al.*, 1996). We are trying to (a) sort out and use the available data to put temporal scale consideration into the analysis of the watershed, (b) analyse macro-scale natural phenomena that influence the water regime, and (c) decide what research is needed to carry out the stand level studies.

DESCRIPTION OF THE AREA

The 30 km long river collects water from its 91 km^2 catchment situated in southwest Slovenia. The river flows into the Gulf of Trieste Bay in the northern most part of the Adriatic Sea. The area is geologically composed of Eocene flysch with calcareous soils on the hills and calcareous alluvium with alluvial soils. The yearly average precipitation is 1150 mm. The average annual temperature is 14 °C on the coast and 10 °C on the upper eastern side of the catchment. The forested area of the catchment consists mostly of *Ostryo-Quercetum pubescentis* with some fragments of *Carpinetum orientalis croaticum*. The tree species in the valley are *Populus tremula*, *Populus alba*, *Populus nigra* and *Salix purpurea*. Pastures and grasslands are being overgrown by *Cotinus cogygygria*, *Juniperus communis*, *Coronilla emeroides*, *Ostrya carpinifolia*, *Quercus pubescens*, *Fraxinus ornus* (Kaligaric, 1997). The catchment is sparsely populated; depopulation processes have only recently been stopped. No industry and no new urban areas have been developed in the catchment. Agricultural production has been intensified in some areas. Anti-erosion measures were the only technical works implemented by the water management in the past. Five sand trap dams were constructed and almost 200 small weirs built in the headwater network in the 1975–1985 period (Globevnik *et al.*, 1995). Parts of the area were afforested to enhance natural succession on the slopes. Only very recently, some 500 metres of the river have been regulated and embanked.

METHODS

The land use and water regime characteristics have already been described (Globevnik *et al.*, 1995; Globevnik *et al.*, 1997 and Globevnik *et al.*; in press). The analyses of land use changes were made by the image processing of aerial photographs (1971, 1985, 1994, scale 1:10,000) and integration of non-spatial historical data. Detailed river morphological changes have been studied with the use of grey scale aerial photos from the years 1975, 1992 and 1994 (GURS and MOK; GURS). The images have been obtained for the 10 km long section at a scale of 1 pixel per 0.5 m^2. The images from 1975 and 1994 have been geo-referenced and rubber sheeted on a Gauss Krüger coordinate system and further analysed using GIS techniques. The commercial packages Idrisi and AutoCad Map 2 have been used for these purposes. The images from 1992 have already been prepared as ortophoto digital images (GURS and MOK). The river morphology and data on the stream vegetation cores have been manually vectorized and classified. Four classes have been defined. The first is the gravel bar class (white to light grey reflectance). The second is the open water class (black or very dark grey reflectance). The last two are vegetation classes, one being bush/tree vegetation, the second agricultural land (grassland, fields, vineyards). The classification has been validated through field inspections. Since the aerial photos were taken at times of similar hydrological conditions (low summer discharge: June 1975, 0.080 m^3 s^{-1} and June 1994, 0.060 m^3 s^{-1}), the sum of the open water and gravel bar surfaces represents the permanently active channel width (termed the channel bottom width). We determined this channel width every 100 m in order to compare the morphological changes of the channel. The analysed length of the channel is 6.8 km (from 11.3 km from the mouth to the 18.1 km). Figure 1 shows the catchment with the location of the hydrological station and the river sections which have been analysed. On the basis of the results obtained, characteristic micro-level locations were determined for future detailed study of changes to the river cross-section and to the sediment granulometry.

RESULTS

In 1971, 21% of the catchment area was covered by tree/shrub vegetation (Globevnik *et al.*, 1996). At that time, rural depopulation and low demographic potential

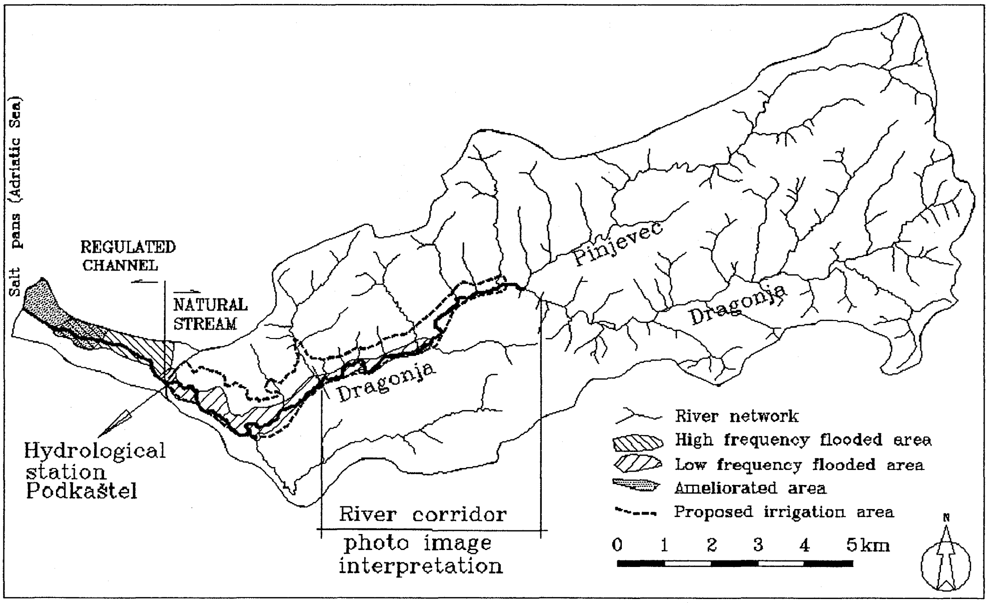

Fig. 1 The Dragonja River catchment.

initiated natural spreading of bushes and trees. In the 1975–1985 period, stabilisation measures of ditches (weirs, small dams), surface erosion protection measures and an afforestation programme were implemented. By 1985, 52% of the area was covered by tree/shrub vegetation and by 1994, 60%. In 1971, surface erosion was severe over 6% of the area, while today only 1% of the area is subject to severe surface erosion. Erosion of headwater ditches (deep and side erosion) has also decreased. There is more than 60% less material eroded today (7900 m^3 $year^{-1}$) than in 1971 (17500 m^3 $year^{-1}$).

The annual flow rate at Podkaštel station (92 km^2) is 1.712 m^3 s^{-1} with the highest measured peak flow of 98 m^3 s^{-1} (period 1960–1995). The linear trend regression analysis of the hydrological regime has shown that there is a 3.5% reduction of the discharge every year (Globevnik *et al.*, 1997). The reduction is the greatest in the summer months. Changes have occurred in the frequency of extremely low and high discharges. The average number of days during the analysed period with low discharges (less than 0.5 m^3 s^{-1}) is 187, but the trend analyses show that by the year 2000 there will be 100 more days with low discharges, if this trend continues. At present, there are 96 days per year when discharges are higher than 1.5 m^3 s^{-1}, while in the near future, if the trend continues, this number will decline to only 19 days per year. It was concluded that the reduced overall discharges, greater frequency of low and reduced frequency of high discharges, correlates with higher demands for water by the vegetation, as there were no significant changes of climatological parameters.

Figure 2 shows the extent of open water surface (water surface that is not shaded by bank vegetation) with gravel bars and vegetation along the river side (bush/tree, agricultural land) for 1975 and 1994. The quantitative results are shown in Table 1. The active channel width extent in 1994 is 60% smaller than that in 1975. The agricultural land area along the river banks has been reduced by 25%. There was

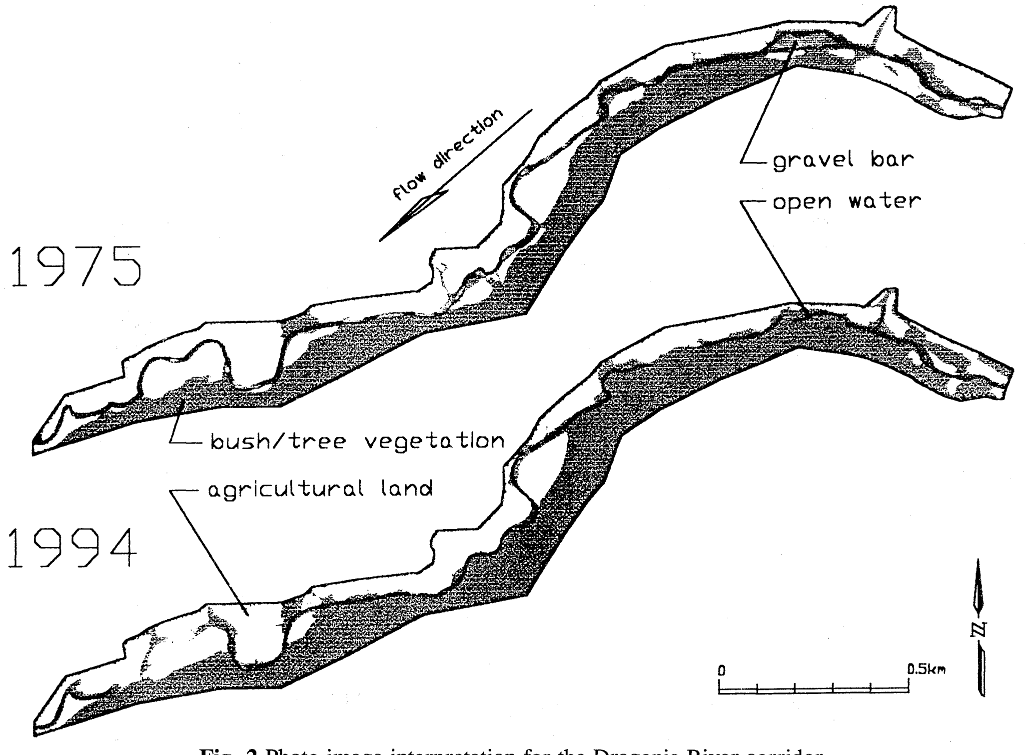

Fig. 2 Photo image interpretation for the Dragonja River corridor.

30% more tree/bush vegetation cover in 1994 than in 1975. The average channel bottom width (see Fig. 3) has been reduced by 24% in subsection A (from 17 m to 13 m), 29% in subsection B (14.5 m to 10.5 m), 55% in subsection C (18 m to 10 m) and 34% in subsection D (from 21 m to 14 m). In subsection C, two parallel streams have been almost cut off (length 300 and 450 m), whereas in subsection D, a 150 m long channel with a gravel bar that was active, today forms an island with a flow channel to either side.

DISCUSSION AND CONCLUSIONS

The erosion processes were intensive 20 years ago due to the sparse vegetation cover and locally intensive soil erosion. Consequently, the river has had intensive sediment transport dynamics. With anti-erosion measures, including afforestation, and natural

Table 1 Spatial extent of four image classes for the river corridor.

	1975	1994
Gravel bars	2.2 ha	0.1 ha
Open water surface	10.0 ha	4.8 ha
Agricultural land	89.2 ha	67.5 ha
Bush/tree vegetation	99.8 ha	128.8 ha

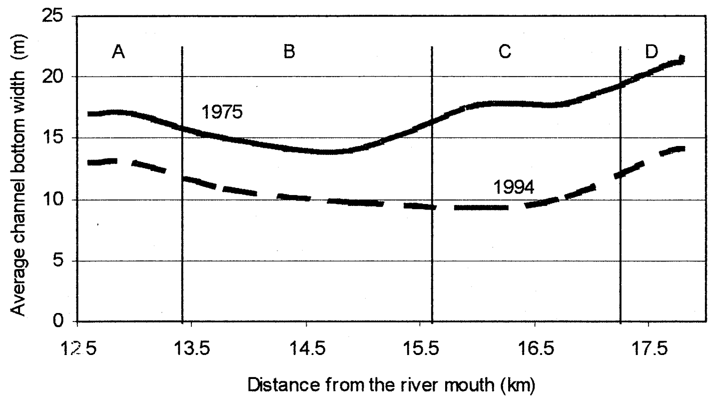

Fig. 3 Average channel bottom width in 1975 and 1994.

re-vegetation processes, the river morphology has changed. Erosion has been reduced by more than half between 1975 and 1994, so there is considerably less material transported to the river. Furthermore, the reduced frequency and duration of high water flows have also reduced the river bottom sediment transport dynamics and bank erosion. Interpretation of aerial images from 1975 and 1994 show that major gravel bars have been stabilized and overgrown. Average channel width in dry periods (channel bottom area that is not overgrown or covered by bank vegetation) in 1994 is 60% smaller than it was in 1975. Today almost half of the major gravel bar areas on the most active river sections are stabilized by vegetation and smaller gravel bars have almost disappeared. No additional field surveys were carried out to identify changes in the river morphology and environment. Using a reasonably simple approach (spatial analysis of different time horizon aerial images and analysis of hydrological data), the extent of changes to the hydrological and morphological character of the river has been demonstrated. It is assumed that the reduced open channel width, the rich bank vegetation, the smaller gravel bars and the longer dry periods, have changed the ecological conditions in the water habitat and reduced their extent. The competition for water and related habitats is becoming greater. Erosion prevention measures, forest resource development, intensive agriculture and water abstraction may lead to further deterioration of the river morphology dynamics and limit water availability for river biodiversity. The proposed irrigation project may pose an even greater risk to sediment transport dynamics, river morphology and water flow dynamics. Due to these facts, the management of natural resources in the Dragonja Catchment should be carefully planned and implemented. Furthermore, due to the high level of biodiversity and wilderness, the area should be managed mainly for landscape conservation and designated as a Protected Landscape Area. Integrated water management should be considered and sustainable resource management and development options should be put into practice.

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