The impact of erosion control measures on runoff processes

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Abstract Water supplies in Serbia are based primarily on reservoir storage in protected areas. The reservoir catchments are located in hilly-mountainous regions in order to avoid the water quality problems associated with urbanization and agricultural production. One of the most important conditions for the continued effective use of such reservoirs is protection of their storage from sedimentation. Erosion problems are widespread in Serbia. 86% of the territory suffers from erosion processes of varying intensity and the total annual production of eroded material is *ca.* 40×10^6 m^3 $year^{-1}$. Erosion control is based on the construction of control structures on torrents and bio-technical works (afforestation of bare lands and restoration of degraded forests and pastures). There is currently a need for afforestation of 600 km^2 of bare land in the catchment areas of reservoirs which are currently under construction or planned. Land use change (from bare land or degraded forest to stable forest), whilst providing erosion control, also has a significant influence on runoff processes through its influence on the hydrological cycle. The impact of anti-erosive afforestation on runoff processes has been studied in the experimental catchment M-III, located on the Goc mountain n central Serbia during the period 1980-1995.

INTRODUCTION

The sustainability of surface storage, for water supply in Serbia, depends on its protection from sedimentation. Production of eroded material amounts to 400-1000 $m^3\,km^{-2}$ $year^{-1}$, and almost 8×10^6 m^3 reaches the river system. Much of this is deposited downstream. Erodible rocks cover 82.8% of the territory of Serbia, and 70.6% of the territory is characterized by slopes greater than 5%: Bare land and degraded forests occupy 14 010 km^2, and land use frequently takes only limited account of erosion control. It is clear that reservoirs face major sedimentation problems, especially in southeastern Serbia (Zavoj, Prvonek, Selova, Barje). The continental precipitation regime (higher precipitation in the warmer part of the year, months IV-X), the high frequency of storm rains of strong intensity ($I > 0.2$ mm min^{-1}) and short duration ($T < 24$ h) and with daily depths of precipitation $P >$ 30 mm, the lack of good vegetation cover, the small water storage capacity of the soil and the high slope of the terrain, result in the occurrence of torrential floods. The kinetic energy of such torrential floods mobilizes large quantities of bed load and suspended material, which are transported through the river system and deposited downstream.

Reduction of erosion and trapping of material on the slopes, before it reaches the river system is possible by application of anti-erosive afforestation. Newly

Table 1 General hydrological characteristics of the experimental catchment areas.

Catchment		*P* (km)	*L* (km)	*D* (km km^{-2})	*T* (a.m.s.l.)	*C* (a.m.s.l)	*Isr* (%)	*It* (%)
M-I	0.0760	0.400	1.075	6.25	925	835	27.1	22.50
M-II	0.0635	0.325	0.875	8.35	922	862	14.9	18.46
M-III	0.0843	0.625	1.300	6.76	982	780	33.0	32.32

A = area; *P* = perimeter; *L* = length; *D* = drainage density; *T* = highest point; *C* = confluence point; *Isr* = average slope of the terrain; *It* = slope of the bed.

established forest stands have a strong impact on the runoff regime. On the Goc mountain in central Serbia, an experimental hydrological station, M-III, has been established. The catchment area was bare land at the beginning of the research (1980), and in the same year it was afforested. The effects of the anti-erosive afforestation on runoff processes have been evaluated by comparison with two neighbouring catchment areas, M-II and M-III.

THE STUDY AREA

On the Goc mountain, in central Serbia, three experimental catchments have been investigated from 1980 to 1995. Each of them is equipped with a limnigraph, pluviograph, thermograph and hygrograph. The flow measuring structures

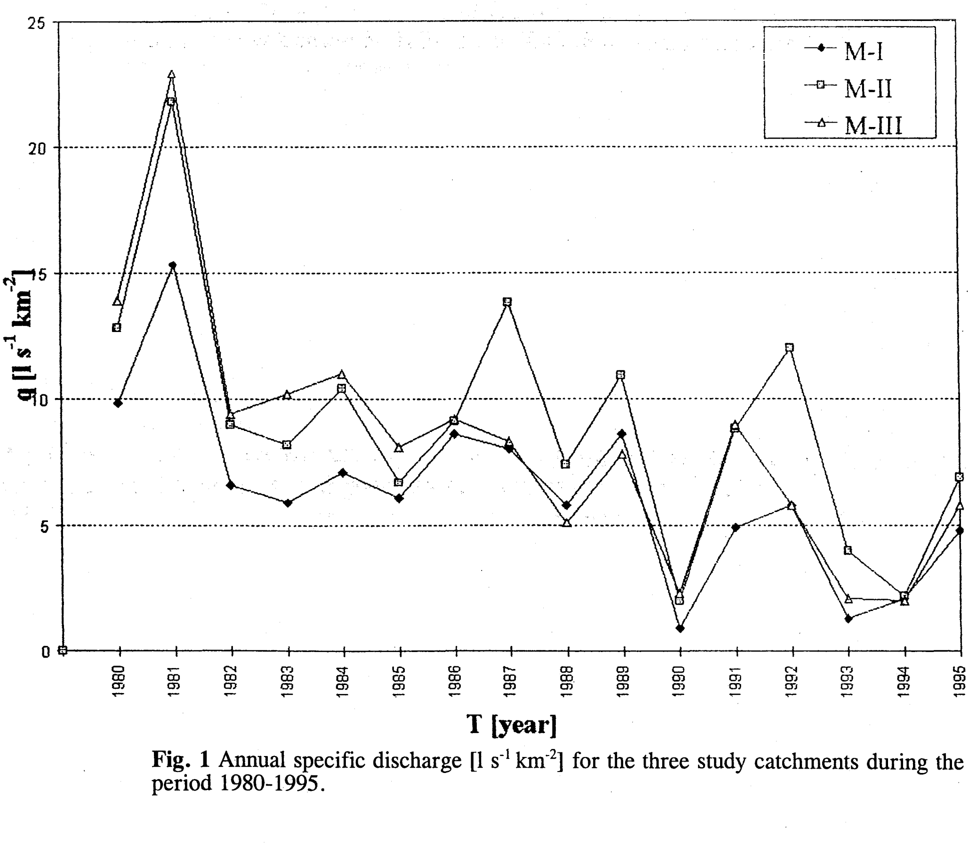

Fig. 1 Annual specific discharge [l s^{-1} km^{-2}] for the three study catchments during the period 1980-1995.

incorporate suitable compensation pools with sediment traps (bed load measuring), and measuring weirs (combination of Cipolleti-Thomson). The main hydrological characteristics of the catchments are presented in Table 1.

The experimental catchment M-III was originally bare land on serpentine rock, with 40% of its surface under *Lasiagrostis calamagrostis* grass. In 1980 it was afforested with *Pinus nigra*. The ground cover now ranges from 40.3-71.9%. The present soils range from the initial phase of soil development on serpentine to skeletal brown soil in the depressions. The tree density is 3000 per ha.

The experimental catchment M-I is planted with 35 year old *Pinus nigra*, *Pinus silvestris*, *Picea abies* and oak. The ground cover ranges from 53-95%, and the area is underlain by serpentine and peridotite rocks. There are five types of soil, ranging from genetically weakly developed (skeletal silicate soils) to well developed brown soils (with layer of litter up to 12 cm deep). The tree density is 2500-3000 per ha.

The microcatchment M-II is under natural meadow-pasture with *Helleboro serbicae*, and *Danthonietum Calycinae*. It is underlain by serpentine rock, on which brown humus-silicate soils have developed.

The natural vegetation of the catchments would be native stands of *Quercetum montanum serpentinicum*, and degraded *Juniperus oxicedrus*. The climate is of a mountain type, with a mean annual precipitation of 822-949 mm, and an average air temperature of 6.01-8.32°C.

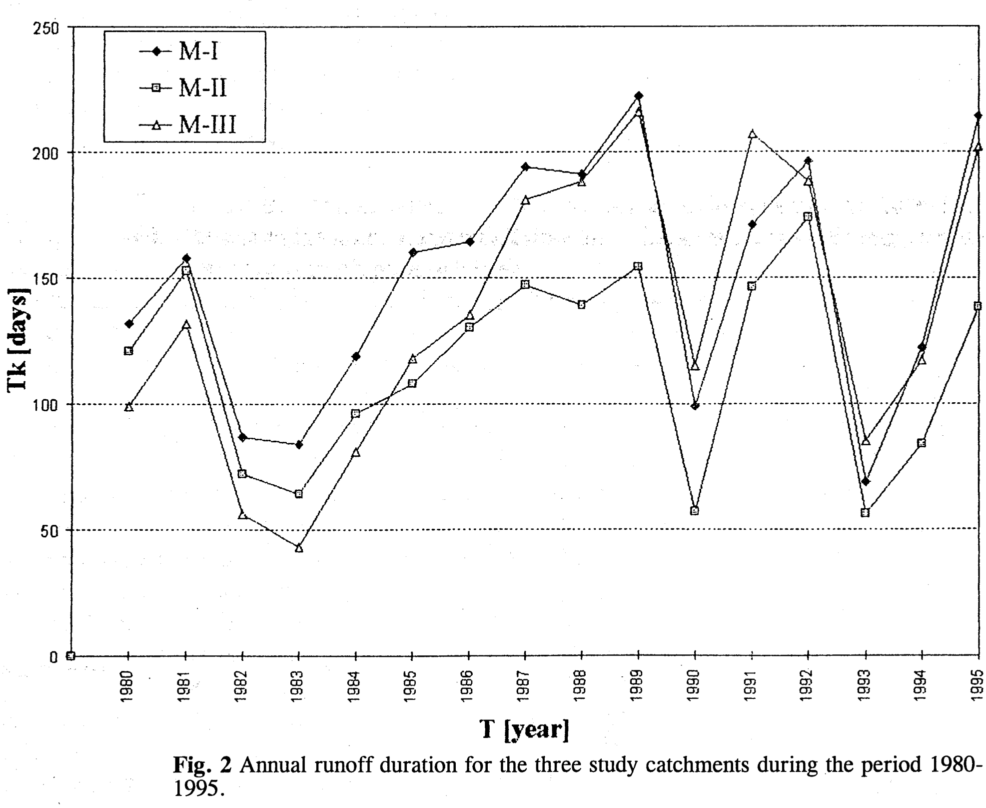

Fig. 2 Annual runoff duration for the three study catchments during the period 1980-1995.

RESULTS

Specific discharge

During the period of observation (1980-1995) the highest values of specific discharge [$l\ s^{-1}\ km^{-2}$], were found on the catchment areas under meadow-pasture vegetation (M-II) and with bare land on serpentine rock (M-III) (Fig. 1). When the stable stand of *Pinus nigra* (M-III) was established (1987 — 8 years after afforestation) the specific discharge decreased, to values similar to catchment area M-I (stable forest stand, 35 years old). Values of specific discharge were lowest for all catchment areas in 1990, as a result of the higher mean annual temperature (6.9-10.6°C) and the extremely low annual precipitation (542.8-579.2 mm). A high value of specific discharge was recorded for catchment M-III in 1991 as a result of the lower mean annual air temperature (6.4°C) and the higher annual precipitation (1018.9 mm).

Runoff duration

Runoff duration (Fig. 2) is greater for the catchment areas under forest vegetation (M-I, M-III) than for the catchment area under meadow-pasture vegetation (M-II). Until 1984 the shortest runoff duration was associated with the afforested bare land (M-III). During the period 1985-1986 it was associated with the area of meadow-pasture (M-II), whereas from 1987 to 1995 it was associated with the 35 year old stable forest stand (M-I).

CONCLUSIONS

The establishment of stable forest stands (on bare land and instead of degraded forests or pastures) must be seen as a key anti-erosive measure in order to protect reservoir storage capacity from sedimentation.

Generally, forest vegetation increases transpiration and interception but reduces the loss of water by evaporation. It also, influences the development of the soil, and especially its infiltration capacity. The specific discharge is lower but the runoff duration is longer.

A regional research project undertaken on the Goc mountain in central Serbia, indicates that anti-erosive afforestation (with *Pinus nigra)* of bare land on serpentine rock, produced significant effects on the runoff regime after 7 years.