



The Significance of Soil in Watershed Management

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Abstract

According to forecasts the probability, frequency, duration and intensity of extreme hydrological events and soil moisture situations (flood, waterlogging, overmoistening versus droughts sometimes at the same time, in the same place) will be increasing in the future due to: high (and increasing) spatial and time variability, hardly predictable irregularity of atmospheric precipitation, frequency of heavy (intensive) rainfalls; changing rain:snow ratio and quick snowmelt; macro-, meso- and microrelief; changing land use and cropping pattern; soil characteristics.

Under such conditions, as in Hungary, situated in the deepest part of the hydrogeologically practically closed Carpathian Basin – it is an important fact that soil is the largest potential natural water reservoir and a great part of the atmospheric precipitation can be stored in the 0–100 cm layer of the soil. This potential water storage capacity may prevent or reduce the risk of the unfavourable economic/ecological/environmental consequences of climate (especially precipitation) extremes and hydrological events. In many cases, however this potential storage capacity cannot be used efficiently, because:

- infiltration is prevented or limited by full water saturation; frozen topsoil; or a compact, hardly permeable soil layer on or near to the soil surface;*
- the infiltrated water is not stored because of low water retention.*

The consequences of these cases are increasing surface runoff, evaporation and deep-filtration losses, and increasing hazard of extreme water events. Consequently, all efforts have to be made to help infiltration into the soil and the storage of water within the soil in plant available form. These operations are an unavoidable part of efficient soil moisture control, watershed mangement and environment protection.

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Keywords

Drought sensitivity; extreme moisture regime; hydrophysical properties; soil databases waterlogging hazard

I. Introduction

The rational use of natural resources – including water, soil and ecosystems, the geological strata–soil–water–biota–plant–near surface atmosphere continuum –, maintaining their favourable quality and desirable *multifunctionality* are important elements of *sustainable development* and efficient *watershed management*.

The natural conditions of the Carpathian Basin, especially the plains, are generally and relatively *favourable for rainfed biomass production* for food, fodder, industrial raw material and energy. These conditions, however, show extremely high, irregular, consequently hardly predictable spatial and temporal variability, often extremes, and sensitively react to various natural or human-induced stresses (Láng et al., 1983; Várallyay, 1985, 2004a,b, 2006a). The generally favourable agro-ecological potential is mainly limited by three soil factors:

- (1) *Soil degradation processes* (Várallyay, 2000, 2004b, 2006a).
- (2) *Extreme moisture regime*: simultaneous hazard of flood, waterlogging and drought sensitivity (Pálfai, 2000; Várallyay, 2005a).
- (3) *Unfavourable changes in the biogeochemical cycles of elements*, especially of plant nutrients and pollutants (Láng et al., 1983).

The prevention, elimination or at least moderation of these unfavourable processes are important tasks of social and agricultural development, *watershed management* and environment protection (Várallyay, 2006b).

II. Limited water resources, high variability

According to *global assessments* the availability of good-quality water will be one of the main conflict problems of sustainable development and the most important limitation to the extension of biomass production. The „quality of life” depends – to a great extent – on the rational use of limited *sweetwater resources*, becoming a *strategic element of the environment* in many parts of the World. Consequently, the increase of water use efficiency, including a proper watershed management, has particular significance.

It can be forecast with high probability that in future *water* will be the determining (hopefully not limiting) factor of food security and environmental safety in the Carpathian Basin (Somlyódy, 2000; Várallyay, 1988, 1989b). Consequently, the *improvement of water use efficiency* with rational *watershed management* will be one of the key issues of agricultural production, rural development and environment protection (Somlyódy, 2000).

Water resources are limited (Pálfai, 2000; Somlyódy, 2000; Várallyay, 2006a). The average 450–600 mm annual precipitation shows *extremely high, irregular and hardly predictable territorial* (Fig. 1) and *temporal* (Fig. 2) *variability* – even at micro-scale. And there is an increasing hazard of heavy, *high intensity rains*: Figure 3. Under such conditions a considerable part of the atmospheric precipitation is lost by surface runoff, deep downward filtration and evaporation.

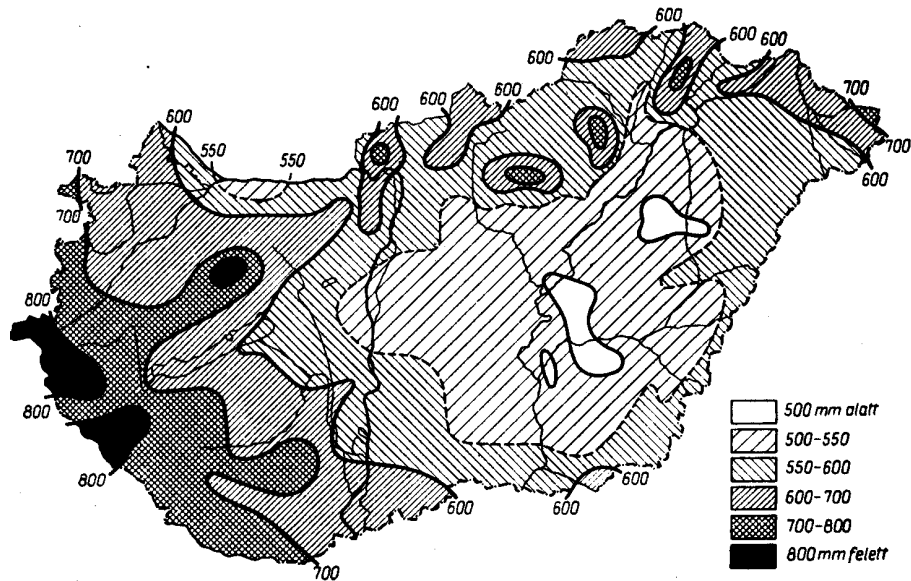


Fig. 1. Distribution of the amount of atmospheric precipitation in Hungary

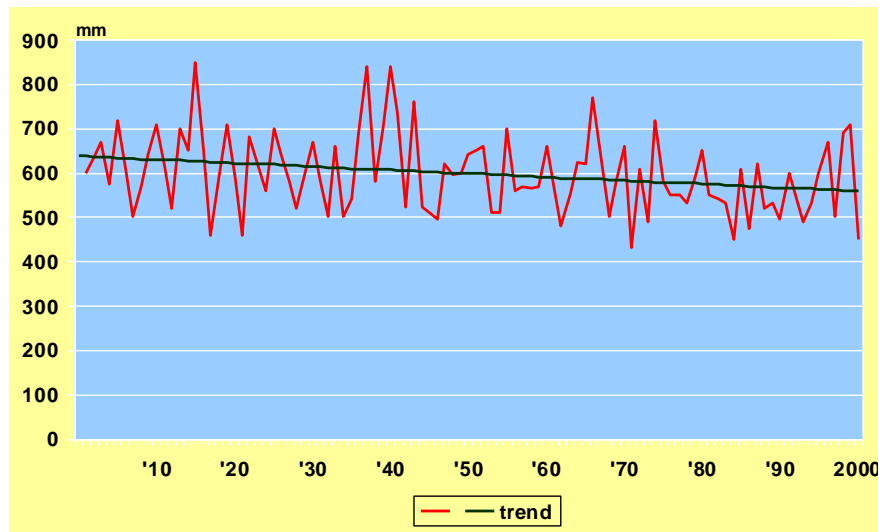


Fig. 2. Long-term fluctuation of atmospheric precipitation in Hungary (Varga-Haszonits, 2003)

Annual precipitation will not be more in the future and its unfavourable spatial and time distribution will even be less favourable. The risk, probability, frequency, duration and intensity of extreme weather and hydrological events and moisture situations is expected to increase (Várallyay, 2000, 2006b). The available quantity of *surface waters* (rivers) will not increase, particularly in the critical low-water periods (Somlyódy, 2005). A considerable part of the *subsurface waters* (especially in the lower parts of the Basin) cannot be used for irrigation because of their poor quality (salinity, alkalinity, sodicity) (Szabolcs et al., 1969; Várallyay, 1974; Várallyay & Rajkai, 1989). Another part is not utilizable because of environmental regulations. (E.g. preventing the sink of the water table and its unfavourable ecological consequences, like the serious „desertification symptoms” in the Danube–Tisza Interfluvial sand plateau.

The annual water balance is negative in the lowland: 450–600 mm precipitation vs. 680–720 mm potential evapotranspiration. The negative water balance is equilibrated by horizontal inflow (on the

surface as runoff, in the unsaturated zone as seepage; and in the saturated zone as groundwater flow), which leads to the *accumulation* of soluble constituents. In addition to the hardly predictable atmospheric precipitation pattern, there are to other reasons of *extreme soil moisture regime* are:

- the heterogeneous *microrelief* of the „flat” lowland;
- the highly variable, sometimes mosaic-like *soil cover* and the unfavourable physical and hydrophysical properties of some soils (mainly due to heavy texture, high clay and swelling clay content, or high sodium saturation: ESP, Várallyay, 1985, 2005a).



Fig. 3. The number of 50 mm > daily precipitation sums in the period January 1980 to May 2005.
Legend: number of days.

III. Hydrophysical properties of soils

According to our comprehensive assessment (Várallyay, 1985; Várallyay et al., 1980) 43% of Hungarian soils can be characterized by unfavourable, 26% by moderately (un)favourable and 31% by favourable moisture regime, as illustrated by Figure 4, indicating the main reasons of various moisture regimes, as well.

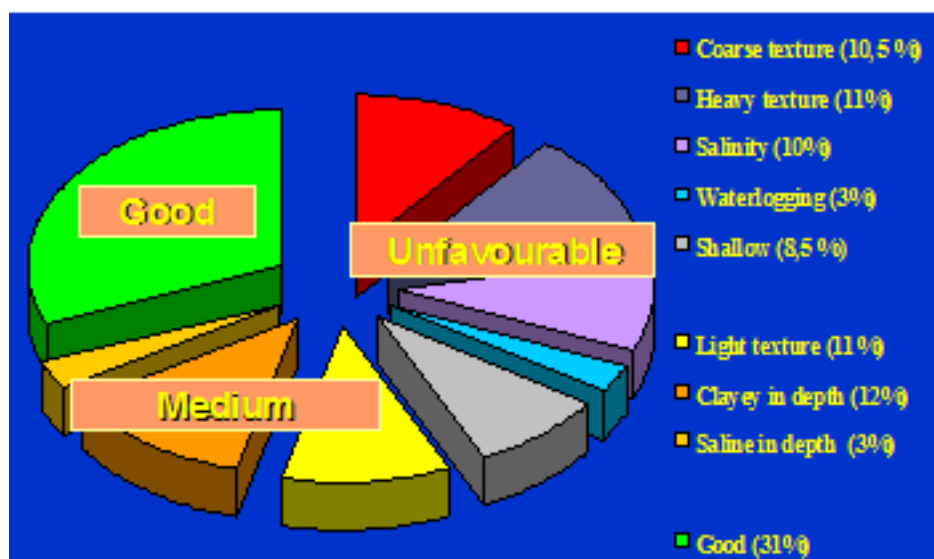


Fig. 4. Distribution of soils according to their moisture regimes in Hungary

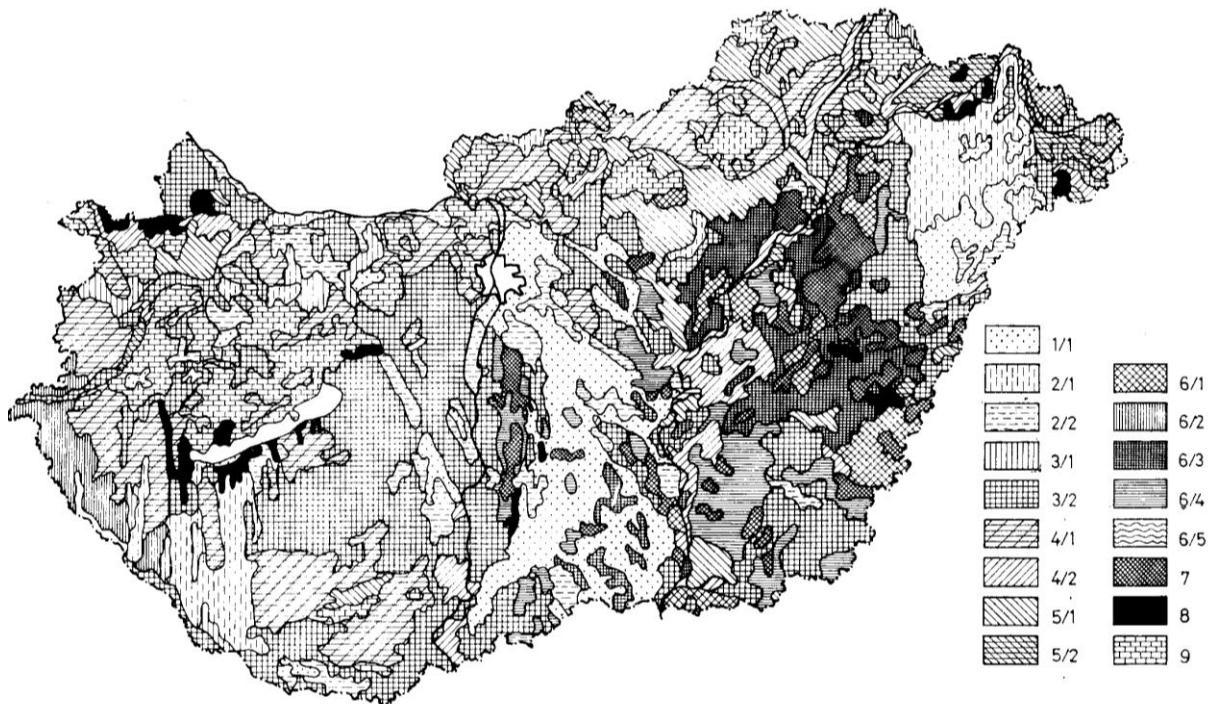


Fig. 5. Hydrophysical characteristics of soils in Hungary.

The 9 main soil water categories are as follows: 1. Soils with very high infiltration rate (IR), permeability (P) and hydraulic conductivity (HC); low field capacity (FC); and very poor water retention (WR). 2. Soils with high IR, P and HC; medium PC; and poor WR. 3. Soils with good IR, P and HC; good FC; and good WR. 4. Soils with moderate IR, P and HC; high FC; and good WR. 5. Soils with moderate IR, poor P and HC; high PC and high WR. 6. Soils with unfavourable water management: low IR, extremely high WR. 7. Soils with extremely unfavourable water management: very low IR, extremely low P and HC; and very high WR. 8. Soils with good IR, P and HC; and very high FC. 9. Soils with extreme moisture regime due to shallow depth. The main profile variants: (1) texture becomes lighter with depth (soils formed on relatively light-textured parent material): 2/1, 3/1. (2) uniform texture within the profile: 1/1, 2/2, 3/2, 4/2, 5/2. (3) relative clay accumulation in the horizon B: 4/1, 5/1. Profile variants of category 6: 6/1: heavy-textured soils with poor structure and a compact layer formed under the influence of misguided soil management; 6/2: pseudogleys; 6/3: deep meadow solonchets, solonchets turning into steppe formation and solonchetic meadow soils (with an A horizon thicker than 15 cm); 6/4: soils with salinity/alkalinity in the deeper horizons; 6/5: peaty meadow soils.

In the last years a comprehensive soil survey–analysis–categorization–mapping–monitoring system was developed in Hungary. The most important elements of the system are as follows:

- Category system and 1:100 000 scale map of the *hydrophysical characteristics* of soils (Várallyay et al., 1980): Figure 5.
- Moisture regime types of Hungarian soils and their 1:100 000 scale map (Várallyay, 1985): Figure 6.
- Large-scale (1:10000–1:25000) mapping of hydrophysical properties and moisture regime of soils (Várallyay, 1989a).

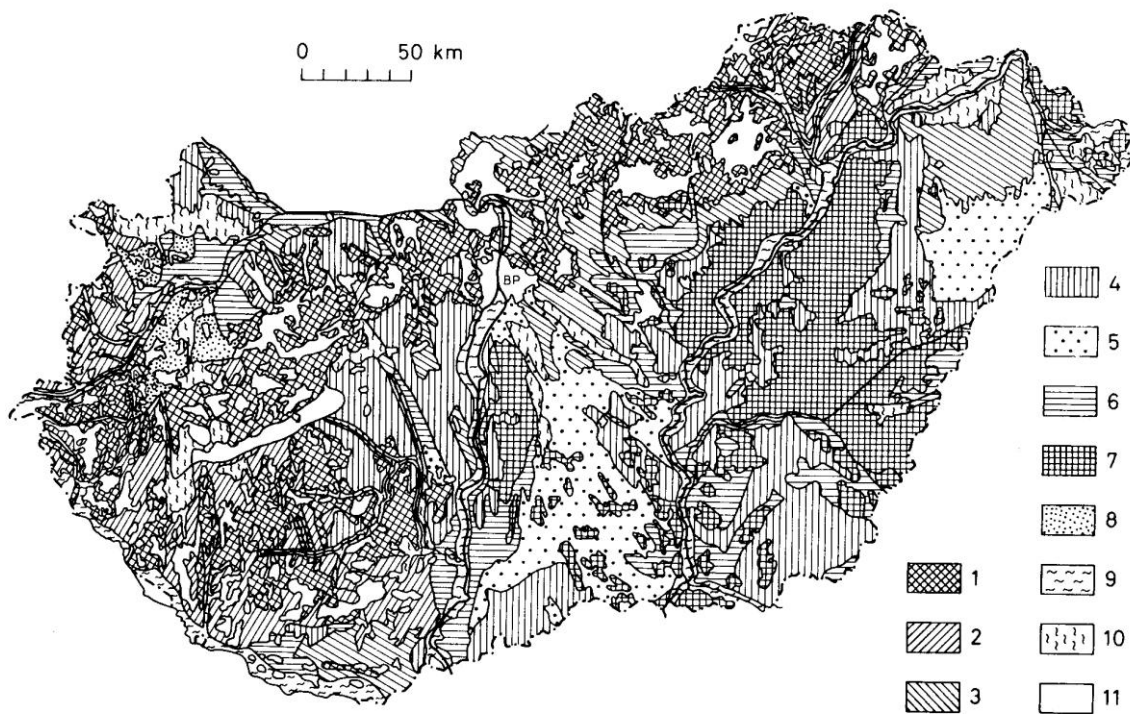


Fig. 6. Map of the main moisture regime types of Hungarian soils

- 1. Heavy surface runoff. 2. Heavy downward flow. 3. Moderate downward flow. 4. Equilibrium type. 5. Rapid filtration type (light-textured soils). 6. Groundwater-wetted type (upward flow is dominant). 7. Extreme moisture regime due to salinity-alkalinity. 8. Extreme moisture regime due to shallow depth. 9. Soils under the influence of rivers and surface streams. 10. Regularly waterlogged areas. 11. Forest with special moisture regime.**

IV. Soil as the largest potential natural water reservoir

Under the given environmental conditions it is an important fact that *soil is the largest potential natural water reservoir* (water storage capacity) of the Carpathian Basin and the Hungarian Plains (Várallyay, 2004a, 2005b, 2006a). The 0–100 cm soil layer may store about 25–30 km³ water, which is more than half of the average annual precipitation (500–600 mm ~ 50–55 km³/year). About 50% of it is „available moisture content”.

In many cases, however, this huge *potential* water storage capacity cannot be utilized because of following reasons:

- the soil pores are not „empty”, they are filled up to a certain extent by a previous water input (rain, melted snow, capillary transport from groundwater, irrigation etc.): “*filled bottle effect*”;
- the infiltration of water into the soil is prevented by the frozen topsoil: “*frozen bottle effect*”;
- the infiltration is prevented or reduced by a nearly impermeable soil layer on, or near to the soil surface: “*closed bottle effect*” (see cases in Fig. 7);
- the water retention of soil is poor and the infiltrated water is not stored in the soil, but only percolates through the soil profile: “*leaking bottle effect*.”

1. Limited infiltration, shallow wetting zone

A) Impermeable layer (crust) on the soil surface



- a) cemented by salts
 - Na salts
 - gypsum
- b) compacted by improper soil management
 - over-tillage, heavy machinery
 - improper irrigation methods

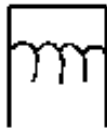
2. Cracking (swelling-shrinkage phenomena)



$IR \approx \infty$
 $\frac{GW}{GW_0}$

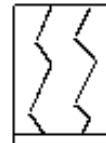
- Dry conditions (shrinkage, cracking)
 - filtration losses
 - rising water table
 - too wet conditions (oversaturation, water-logging)
 - secondary salinization/alkalization from the groundwater (in case of stagnant, saline or alkaline groundwater)
 - evaporation losses (drying of deep layers)

B) Impermeable layer near to the soil surface



$IR \approx 0$

- a) solid rock
- b) hardpans (fragipans, duripans, orstein, ironpan etc.)
- c) layer cemented by exch. Na^+ , clay, $CaCO_3$ and other factors (clay-pan, concretionary horizons, petrocalcic horizons, etc.)
- d) layer compacted by improper soil management (plough pans, etc.)



- Wet conditions (swelling)
 - a) high amount of clay
 - b) high amount of expanding clay minerals
 - c) high ESP



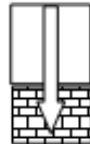
extreme water regime

- oversaturation (aeration problems)
- waterlogging problems
- surface runoff – water erosion
- drought sensitivity

3. Low water retention



$IR, K \gg FC$
sands



Shallow soils
on gravel
on fragmented rocks

- filtration losses
- ↓
- drought sensitivity

Fig. 7. Limiting factors of water storage in soil

The schematic map of these infiltration–water retention limitations is given in Figure 8. These limitations are responsible for the contradiction of the huge potential water storage capacity and the frequent extreme hydrological events, the simultaneous hazard of floods, waterlogging, over-moistening and drought sensitivity, sometimes on the same place, within the same year, is a characteristic feature of the Carpathian plains. Consequently: the moderation of this contradiction is an important task of rational and efficient watershed management.

V. Control of soil moisture regime in efficient watershed management

The flow chart, showing the stages of the planning and realization of successful watershed management (including soil moisture control) is presented in Figure 9.

Under the natural conditions of the Carpathian Plains, the rational watershed management, the risk reduction of extreme hydrological events (floods, waterlogging, over-moistening vs. Drought) requires an efficient soil moisture control. All efforts have to be made to establish a „two-way” („double face”) moisture regulation to: help water infiltration into the soil; help water storage within the soil in plant

available form; drain the surplus amount of water from the soil profile and from the area (vertical and horizontal drainage).

The main possibilities and methods of this moisture control are summarized in Table 1. Most of these „moisture management actions” are – at the same time – efficient environment control measures (Table 1) (Várallyay, 2004b, 2006a).

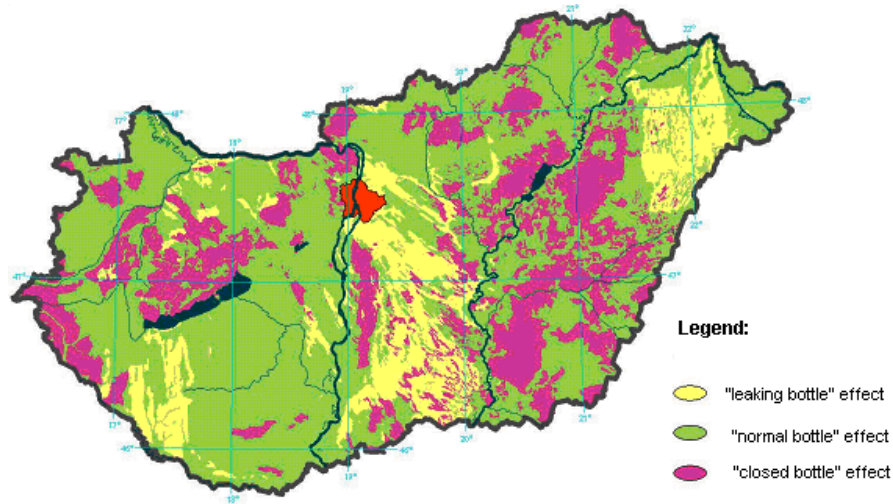


Fig. 8. Limited infiltration rate and water storage capacity of soils in Hungary

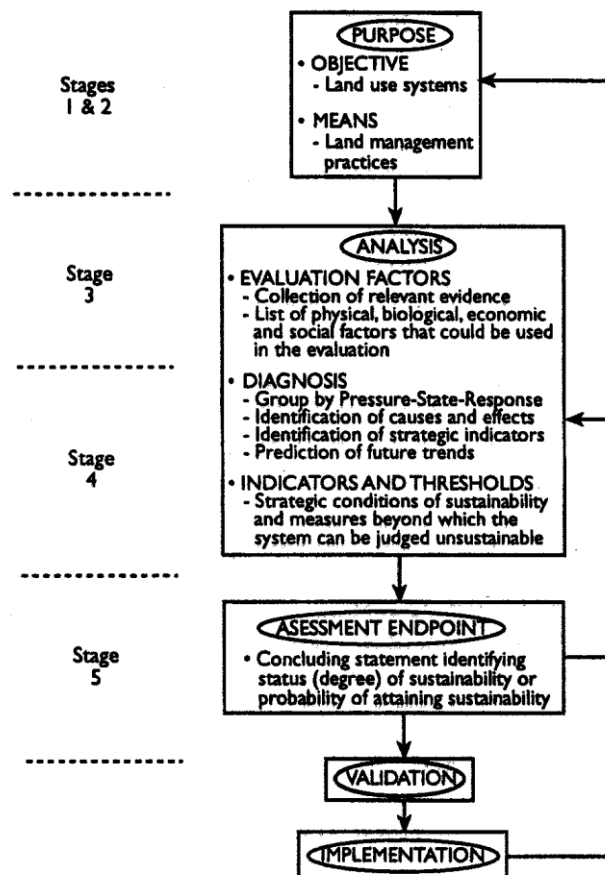


Fig. 9. Flowchart showing the stages of the realization of sustainable land use and soil management

Table 1
Elements and methods of soil moisture control with their environmental impacts

Elements		Methods	Environmental impacts*
Reducing	surface runoff	Increase in the duration of infiltration (moderation of slopes; terracing contour ploughing; establishment of permanent and dense vegetation cover; tillage; improvement of infiltration; soil conservation farming system)	1,1a 5a, 8
	evaporation	Helping infiltration (tillage, deep loosening) Prevention of runoff and seepage, water accumulation	2,4
	feeding of groundwater by filtration losses	Increase in the water storage capacity of soil; moderation of cracking (soil reclamation); surface and subsurface water regulation	5b, 7
	rise of the water table	Minimalization of filtration losses (\uparrow); groundwater regulation (horizontal drainage)	2,3 5b,5c
In-creasing	infiltration	Minimalization of surface runoff (tillage practices, deep loosening) (\uparrow)	1,4,5a, 7
	water storage in soil in available form	Increase in the water retention of soil; adequate cropping pattern (crop selection)	4,5b,7
Irrigation		Irrigation; groundwater table regulation	4,5c,7,9,10
Surface	} drainage	surface	1,2,3,5c,6,7, 11
Subsurface		subsurface	

Favourable environmental effects		Unfavourable environmental effects
Prevention, elimination, limitation or moderation of:		
<ul style="list-style-type: none"> - water erosion (1) - sedimentation (1a) - secondary salinization, alkalization (2) - peat formation, waterlogging, overmoistening (3) - drought sensitivity, cracking (4) 	<ul style="list-style-type: none"> - plant nutrient losses by: <ul style="list-style-type: none"> • surface runoff (\rightarrow surface waters eutrophication) (5a) • leaching (\rightarrow subsurface waters) (5b) • immobilization (5c) - formation of phytotoxic compounds (6) - "biological degradation" (7) - flood hazard (8) 	<ul style="list-style-type: none"> - overmoistening, waterlogging, peat and swamp formation, secondary salinization/alkalization (9) - leaching of plant nutrients (10) - drought sensitivity (11)

VI. Conclusions

Sustainable watershed management, including an up-to-date soil moisture control requires continuous actions. This permanent control may prevent, eliminate or at least reduce undesirable soil processes and their harmful economical/ecological/environmental/social consequences; utilizing the unique soil characteristic, *resilience*, may satisfy the conditions for the „quality maintenance” of this „conditionally” renewable natural resource.

Control can be efficient only on the basis of comprehensive *risk assessments*, *impact analyses* and exact *prognoses*. These have to be the main research priorities!

The successful prevention, elimination or moderation of undesirable soil degradation processes and extreme moisture regimes can be efficient only in a well-coordinated *multidisciplinary international cooperation* in the Carpathian Basin. The realization of the *sustainability concept* in the rational land use and soil management gives reality for a better life: healthy, good quality food, clean water and pleasant environment.

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