



Soil erosion

Soil erosion

- Probably the most wide-spread soil-related land degradation processes
- **Natural** process, but its **intensity has increased** significantly due to human activities (land use and management, deforestation, agriculture) and so has the **extent of affected areas**
- The main anthropogenic factors stimulating soil erosion are **ploughing/tillage** and deforestation; besides that, overgrazing increases the susceptibility of soil to erosion in arid and semiarid regions; lack of vegetation / plant cover → bare soil is exposed to disruptive forces (water movement and wind)

Soil erosion – consequences

- nutrient loss and decrease in soil productivity: the upper part of soil profile is significant from environmental viewpoint; it is relatively rich in nutrients and organic matter; soil aggregates in the topsoil are often more stable compared to deeper part of the soil; it is also biologically more active; therefore, topsoil loss (depletion) → soil degradation
- not only erosion causes detachment of the particles in upper part (which causes removal of soil organic matter), but deeper parts of soil profile are aerated → increased respiration rate → further decrease of organic matter content
- siltation of rivers, water reservoirs, trenches, creeks, channels (including sewage system)
- water quality degradation: applied fertilizers and agrochemicals contribute to water eutrophication due to runoff and erosion of agricultural land / soil (fertilizers partially end up in streams and lakes instead of soils/plants)

Soil erosion

is an integral part of natural soil genesis / soil formation: the parent material of all soils that are developed from loose sediments had been eroded and subsequently accumulated



Weathering of rocks in mountains produces sediments that are transported downstream by erosion to create fertile soil in the lower parts of the landscape (PZ).

Soil erosion and landslides (difference)

- **Soil erosion:** relatively slow process that affects thin part (layer) of soil profile (but on large area); the time period associated with erosion is longer; the extent of area/land affected significantly by erosion is (from global perspective) much larger compared to landslides

causes: water and air (wind) flows, impacts of raindrops, surface runoff of precipitation

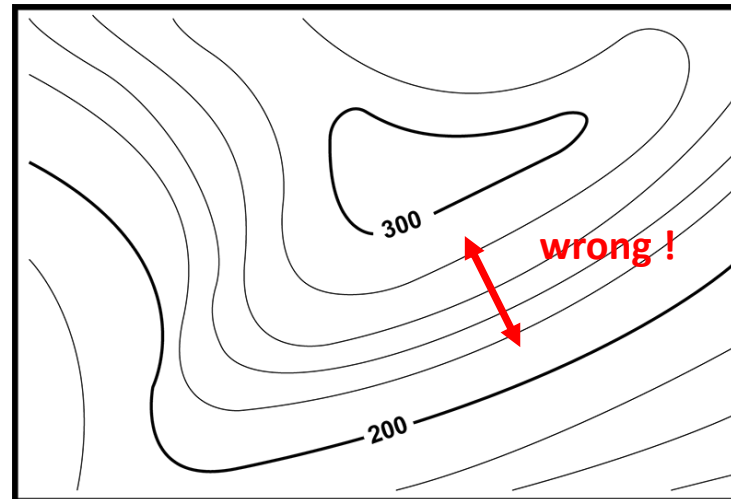
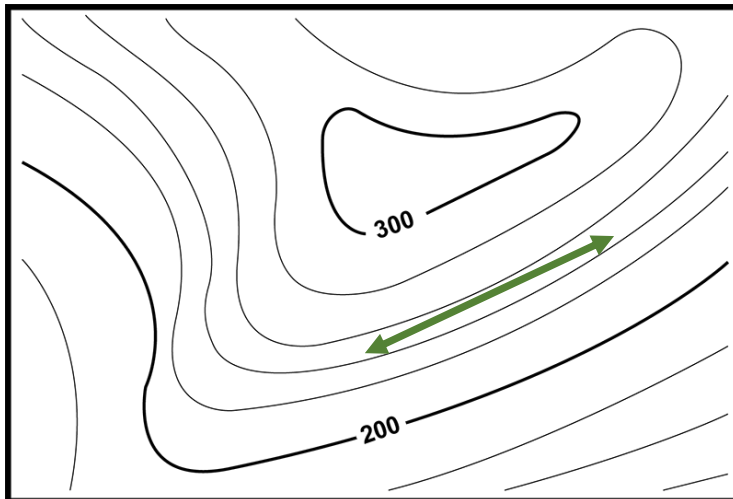
- **Landslide:** abrupt / striking collapse of soil body across several meters of depth (or more), affects smaller areas but vertical interval is greater; landslide does not necessarily refer only to soil, it may refer to collapse of rocks or sediments

causes: saturation of pore system with water (across several meters of depth), freeze – thaw processes, weathering of rocks; unlike soil erosion landslides take place exclusively on slope areas

both may be triggered (driven) by intense (prolonged) precipitation events

Soil erosion in agricultural landscape

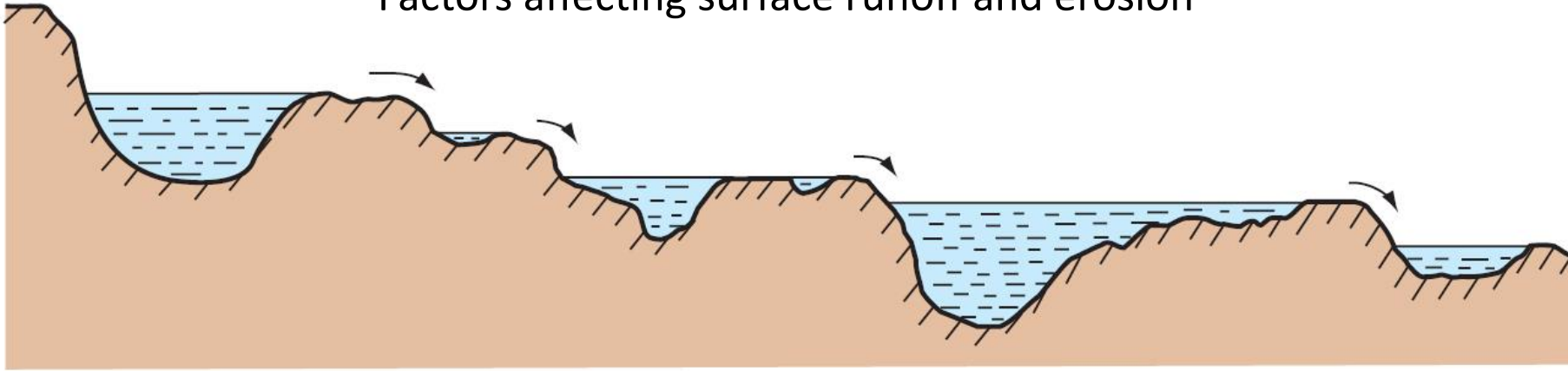
- Tillage – ploughing, especially repeated ploughing to same depth (e.g. 30 cm) → formation of soil layer with high bulk density (called “plough pan”) beneath the depth of ploughing
- Agricultural soils are without vegetation cover during significant part of the year (for example in central Europe 7 or even 8 months per year)
- The most basic prerequisite for limiting the erosion in agricultural areas is ploughing along the contours (**not across** !); limit the ploughing in general: extensive soil tillage does not provide much benefits; ploughing continuous large areas is detrimental for soil quality, there should be some “patches” permanently covered with vegetation in considered area



Water erosion

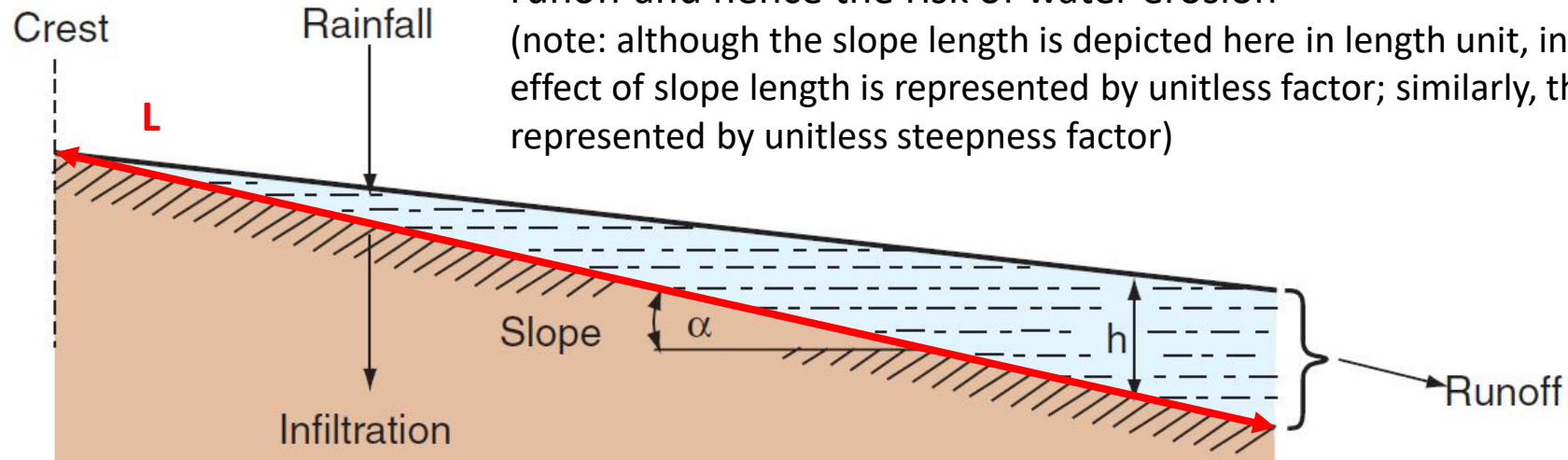
- Whenever the rate of water supply to the soil surface exceeds the rate of infiltration, free water (water excess) either accumulates over the surface or creates surface runoff (overland flow), depending on terrain characteristics and soil properties
- Factors affecting erosion inducement may be divided into the two groups:
 1. **water-related**: precipitation rate and time period associated with continuous precipitation → water amount (typically not controlled by human activity)
 2. **soil/land-related**: surface storage capacity, soil infiltrability, hydraulic conductivity, terrain characteristics (surface roughness) may be affected / partially controlled by management practices, engineering, landscape architecture and planning

Factors affecting surface runoff and erosion



Effect of surface roughness and slope on surface (pocket) storage of rainfall excess. Most of the water thus accumulated generally infiltrates (and some evaporates) after cessation of the rain.

Not only slope (α) itself, but length of the slope (L) also affects positively the runoff and hence the risk of water erosion
(note: although the slope length is depicted here in length unit, in the erosion models the effect of slope length is represented by unitless factor; similarly, the slope α is represented by unitless steepness factor)

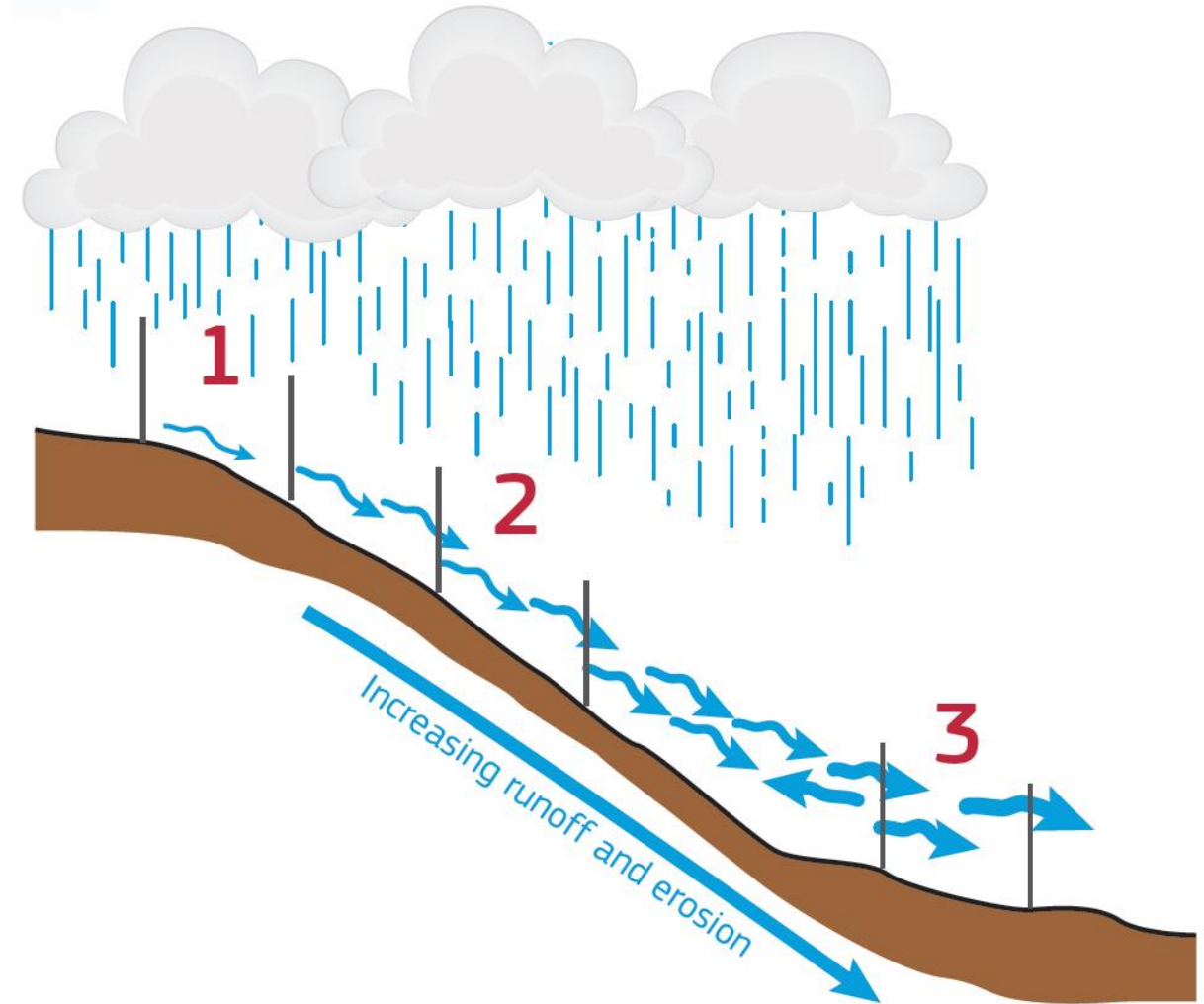


Surface-water excess and sheet overland flow.

Factors affecting surface runoff and erosion

Position on the slope determines erosion effect on soil. Soils in higher locations (1) are affected by water erosion, but the magnitude of erosion on the steepest part (2) is significantly higher. The lowest areas (3) receive the most water and sediment; at times, erosion behaves like a soil-forming factor, transporting the parent material and depositing it at the foot of slopes.

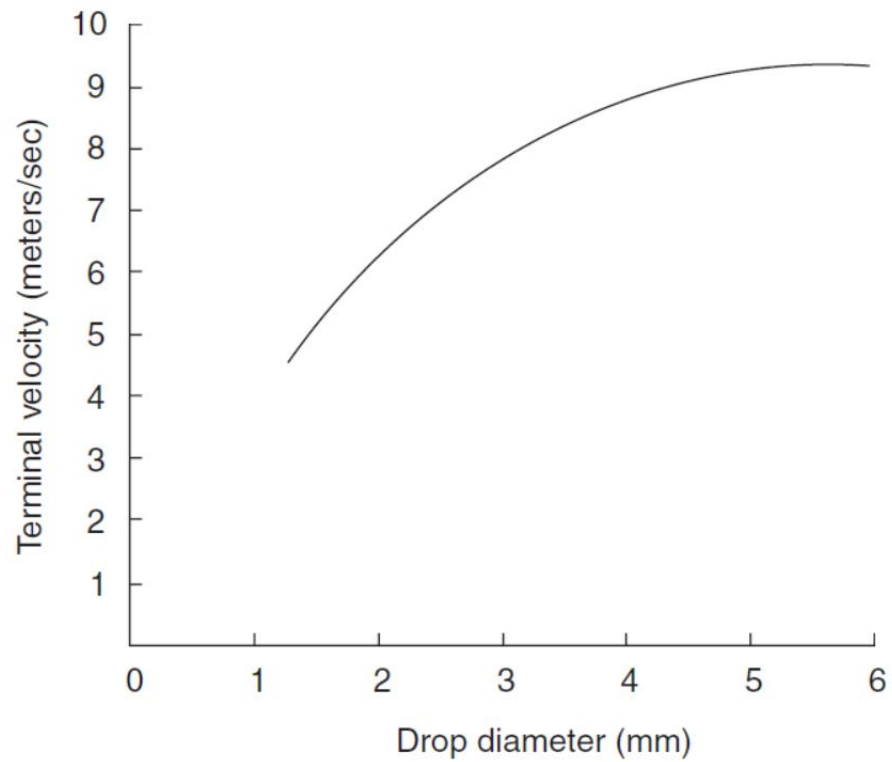
source: Soil Atlas of Latin America and the Caribbean, European Commission – Publications, Office of the European Union, L-2995 Luxembourg, 176 pp.



Erosivity of rainfall and water flow – effect of kinetic energy of (moving) water

- Water erosion is partially stimulated by the impact of raindrops, which cause mechanical disruption of soil aggregates
- In case of long-term precipitation, the surface runoff may turn to overland flow, where soil particles are being detached due to the movement of larger water volumes over the surface
- Overland flow is considered laminar flow in the initial condition, but when the depth and velocity of the flow increase to critical values, turbulence enters the laminar flow domain
(note: criterion for the onset of turbulence is given by Reynolds number – a dimensionless index incorporating the product of the mean fluid velocity in a channel and its effective hydraulic radius, divided by kinematic viscosity)

Erosivity of rainfall



Terminal velocity of raindrops as a function of size. (From Laws, 1940).

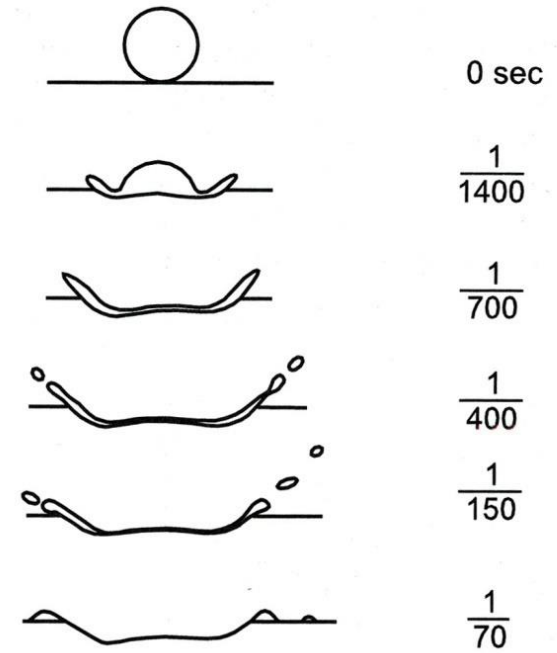


Fig. 15.6. Impact of a raindrop on an erodible soil surface.

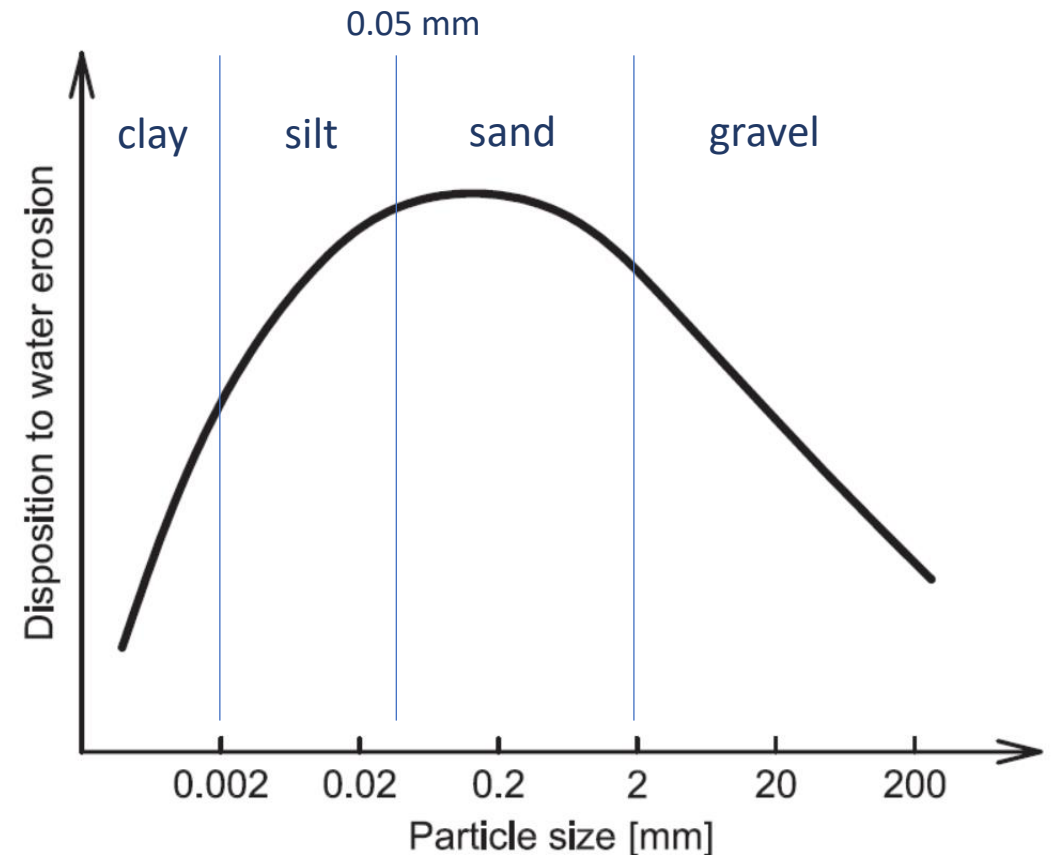


Fig. 15.7. Splash erosion on a sloping soil surface.

Erosivity of rainfall

(role of particle size distribution)

- Susceptibility of soil to water erosion is partially affected by the size of soil particles and their inter-particle forces.
- In this relation, the most susceptible material to erosion are fine sands to silt size particles. In finer particles, internal forces preventing the extraction of the finest particles will prevail, while, on the contrary, in coarser particles the flow pressure will not suffice to extract and transport them
- we should bear in mind that described relation is a simplification and there are also other important factors which affect soil erodibility, such as vegetation cover, slope, or presence of specific minerals in soil, ionic species and organic matter



Erosivity of rainfall and water flow

- Surface runoff may begin as a sheet flow, but as it accelerates and gains in erosive power, it eventually forms channels called rills or gullies.
- Running water tends to scour the soil surface and deepen the channels, which generally form a treelike pattern of converging branches with numerous confluences leading to larger streams.
- Water flow is constrained by shear stresses that exist between the water in immediate contact with the sides and bottom of the channel, the hydraulic resistance of a channel is generally proportional to the area of the perimeter of contact per unit volume of flowing liquid
- This contact area can be characterized in terms of the hydraulic radius (R), or hydraulic mean depth of a channel, defined as the cross-sectional area (A) divided by the wetted perimeter (P)

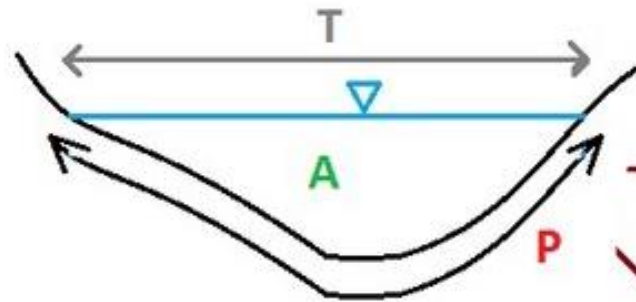


Fig. a: Irregular Flow Cross Section

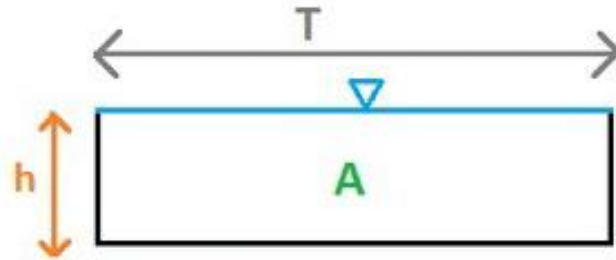


Fig. b: Equivalent section in terms of Hydraulic Mean Depth

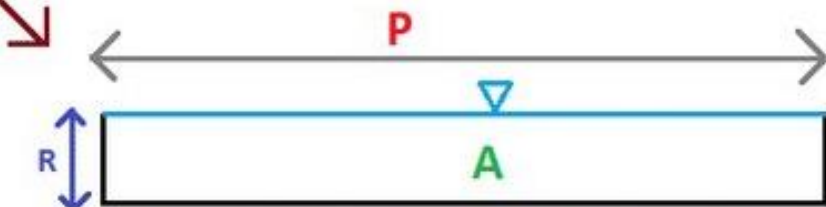


Fig. c: Equivalent section in terms of Hydraulic Radius

T = Top Width of Flow

A = Cross Section Area (Same for all three Figures)

P = Wetted Perimeter

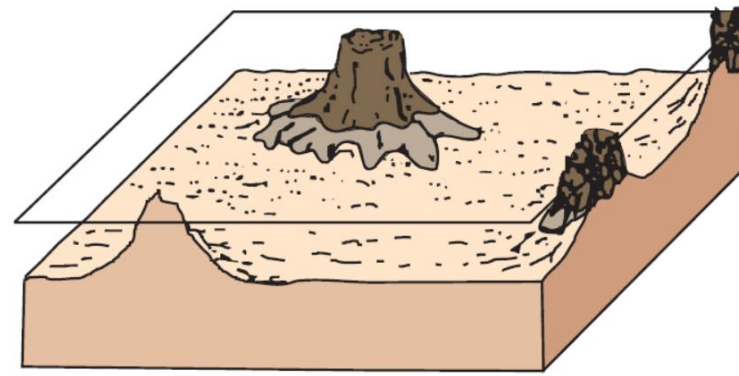
h = Hydraulic Mean Depth = A/T

R = Hydraulic Radius = A/P

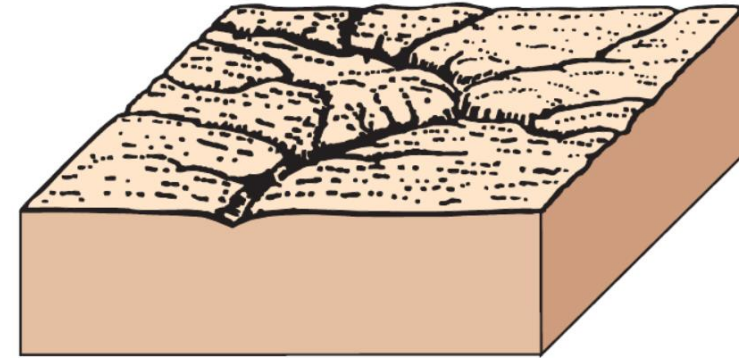
Various forms of water erosion

- Sheet
- Rill
- Gully

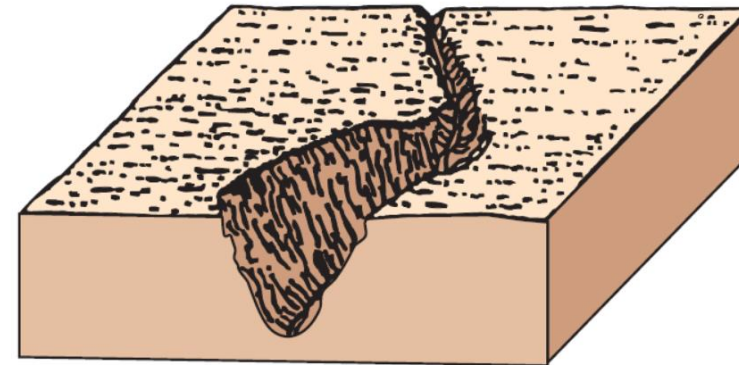
Although different forms (“types”) of water erosion are distinguished, we often experience combined/mixed forms in the field



A. Sheet erosion



B. Rill erosion



C. Gully erosion

Sheet erosion (after fire in eucalypt forest, Australia)



fire consumes understory vegetation and the litter horizon → as a result surface runoff is being formed more easily

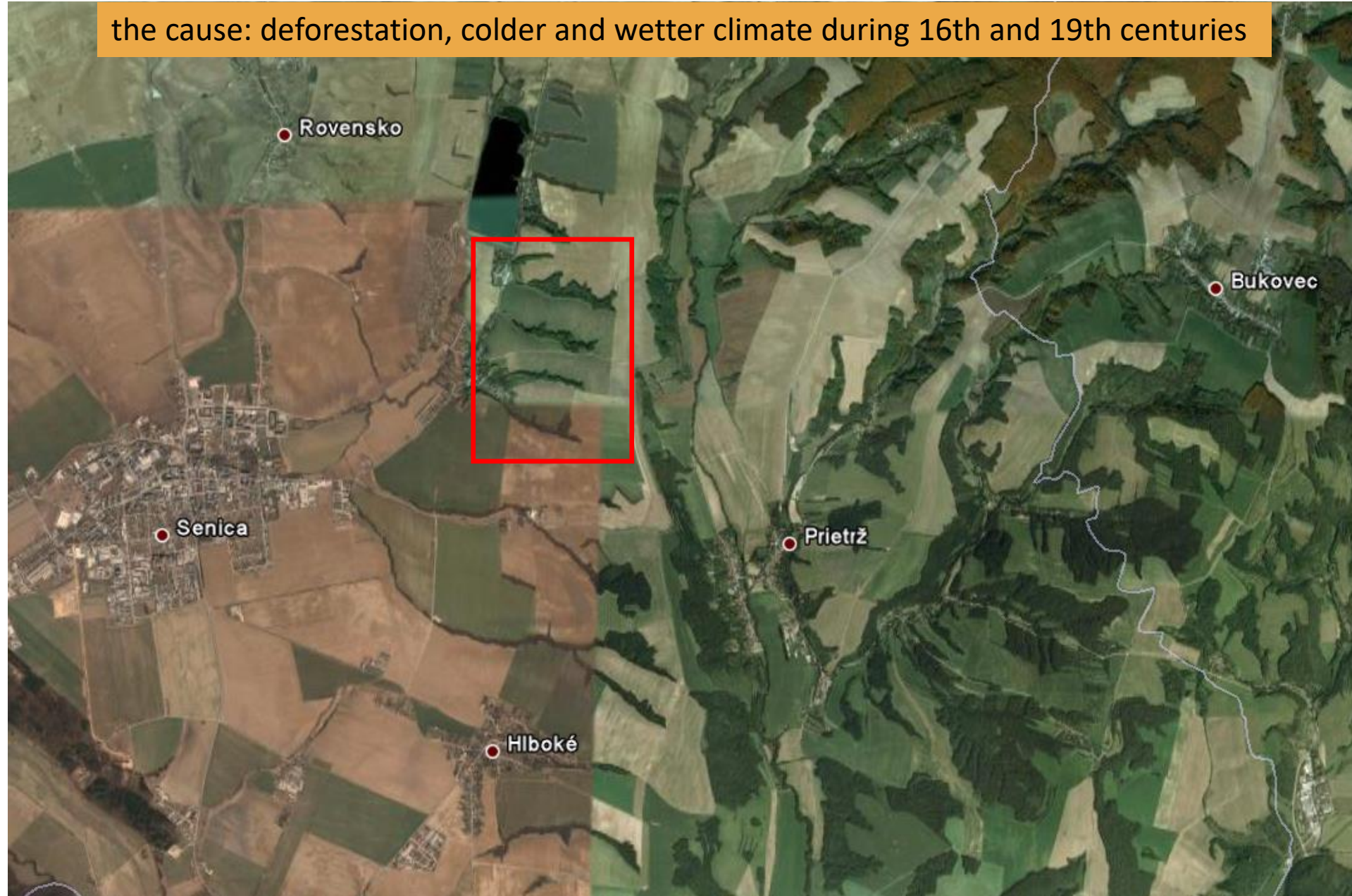
Rill erosion (Šobov - Banská Štiavnica, Slovakia)

the cause: intense soil acidity, plant growth is limited in such conditions (Al toxicity)



Gully erosion (Myjavská pahorkatina hilly land, Slovakia)

the cause: deforestation, colder and wetter climate during 16th and 19th centuries



Gully erosion (Myjavská pahorkatina, Slovakia)

Parent material of soils in some areas is made from weathered marlstone; it is not mechanically stable → soils are prone (susceptible) to erosion



soil parent material: the aggregates are not stable; the particles are being detached quite easily by external forces



Inside a gully: slope stabilization by fast-growing vegetation

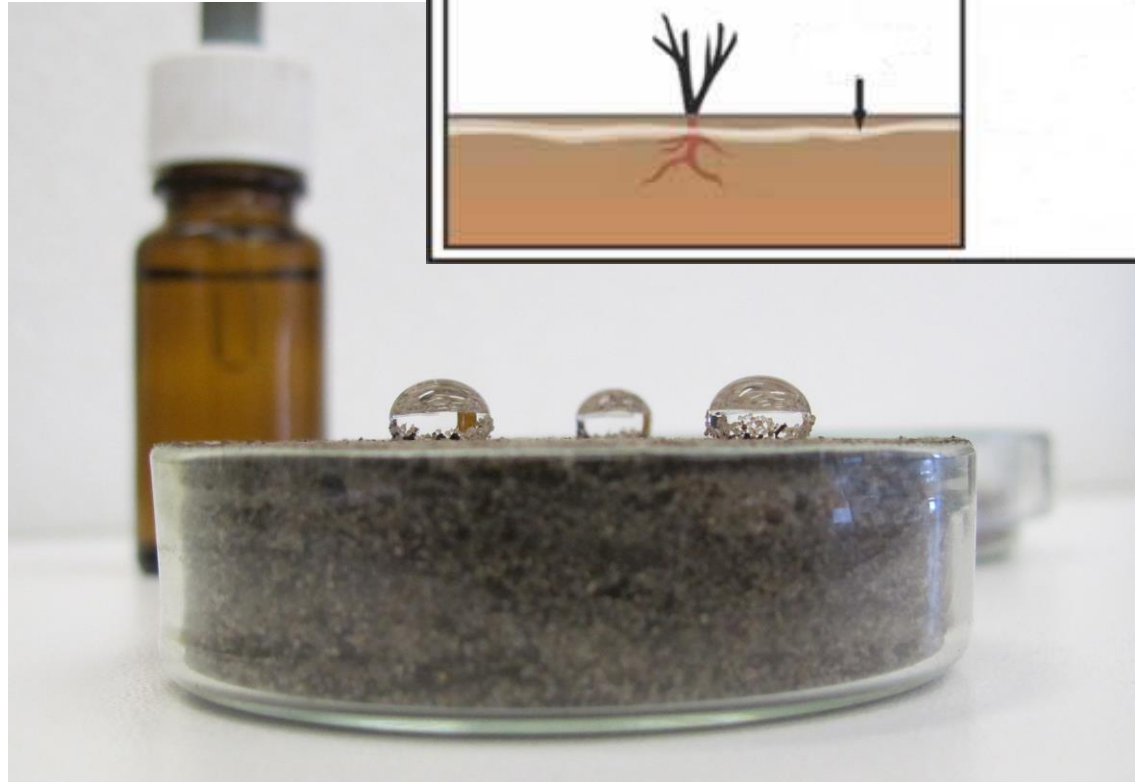
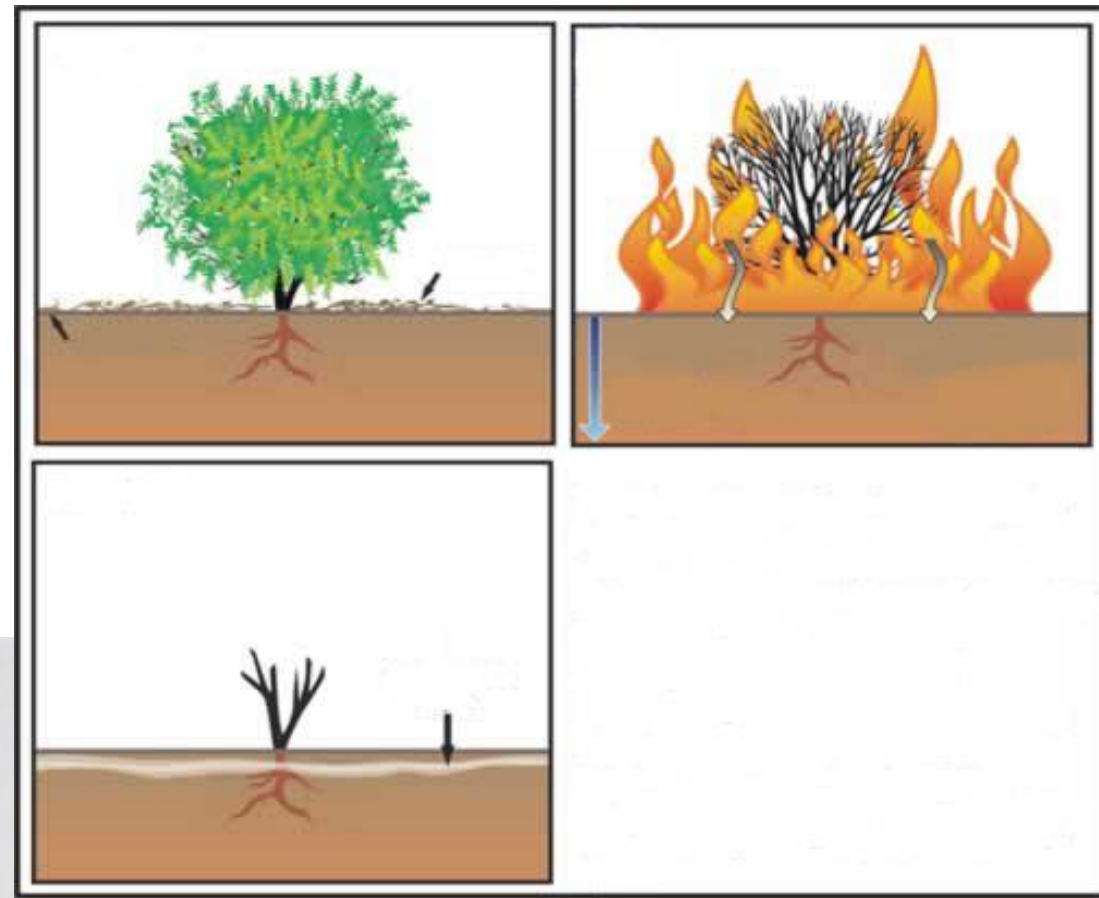




erosion after the fire impact: fire typically consumes vegetation as well as the litter → bare soil is exposed to rainfall, which results to surface runoff; formation of overland flow on fire affected areas is supported also by soil water repellency



soil water repellency is caused by non-polar organic substances (waxes, fatty acids, aliphatic structures), which are covering mineral particles (some of them may evaporate and condensate during fire impact)



Water erosion is affected (controlled) by:

- **precipitation:** intensity / amount, time interval (duration) of precipitation event
- **soil properties:** particle size distribution, hydraulic conductivity / permeability, infiltrability, soil parent material (solid/compact rock vs. unconsolidated – loose sediment)
- **topography** of the area: slope, length of the slope, relief variability and surface roughness
- **vegetation cover:** character and “density” of vegetation (plant biomass / area unit)
- **land use:** soil / land use and management (tillage, urbanization, roads)

Quantifying the risk of (water) erosion (prediction):

Universal Soil Loss Equation (USLE)

The principal equation for the USLE model family is:

$$A = R \times K \times L \times S \times C \times P,$$

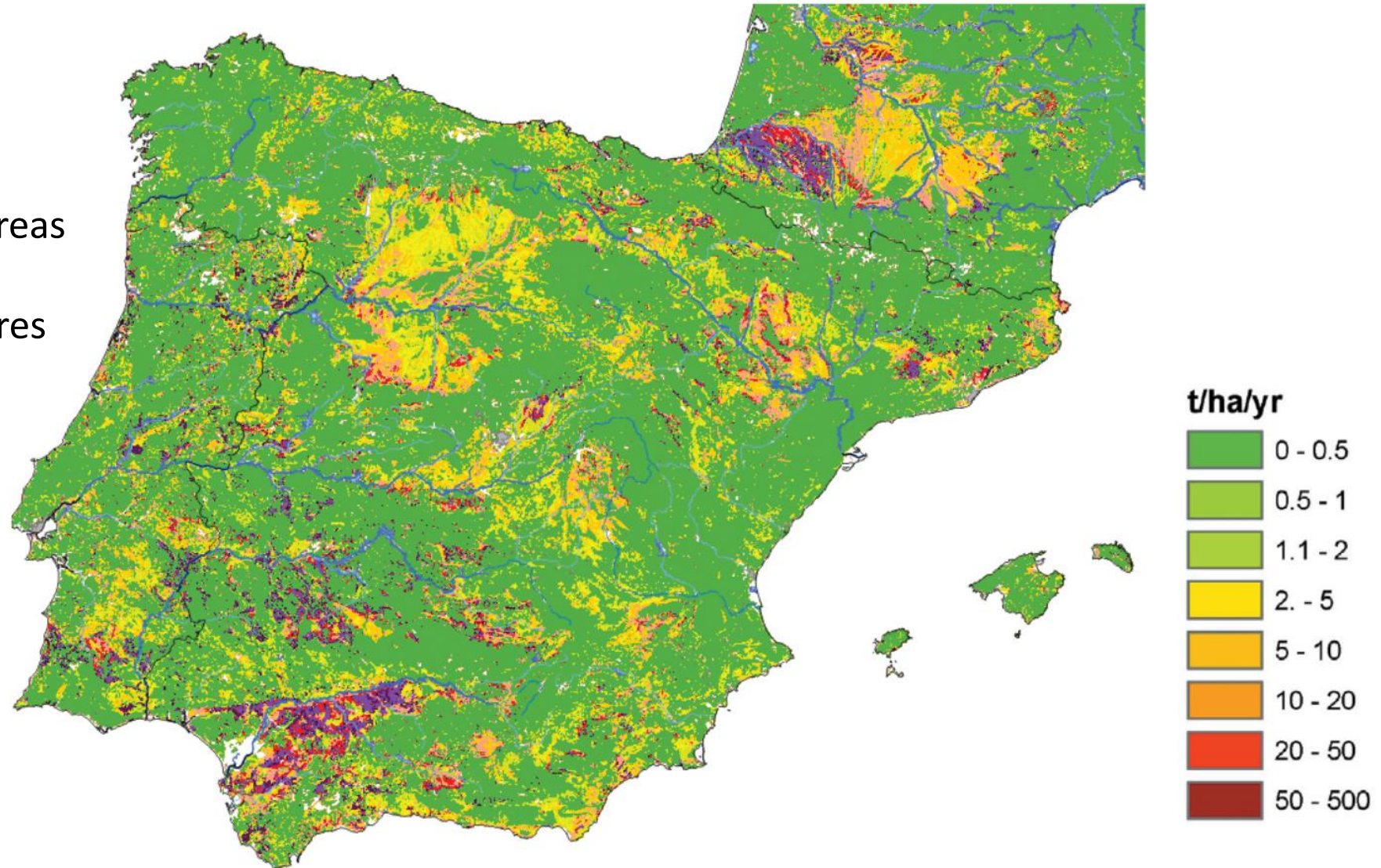
where A is mean annual soil loss (metric tons per hectare per year), R is the rainfall and runoff factor or rainfall erosivity factor (megajoule millimetres per hectare per hour per year), K is the soil erodibility factor (metric ton hours per megajoules per millimetre), L is the slope length factor (unitless), S is the slope steepness factor (unitless), C is the cover and management factor (unitless), and P is the support practice factor (unitless).

further information on USLE equation are in Benavidez et al., 2018. A review of the (Revised) Universal Soil Loss Equation ((R)USLE): with a view to increasing its global applicability and improving soil loss estimates. Hydrol. Earth Syst. Sci., 22, 6059–6086.

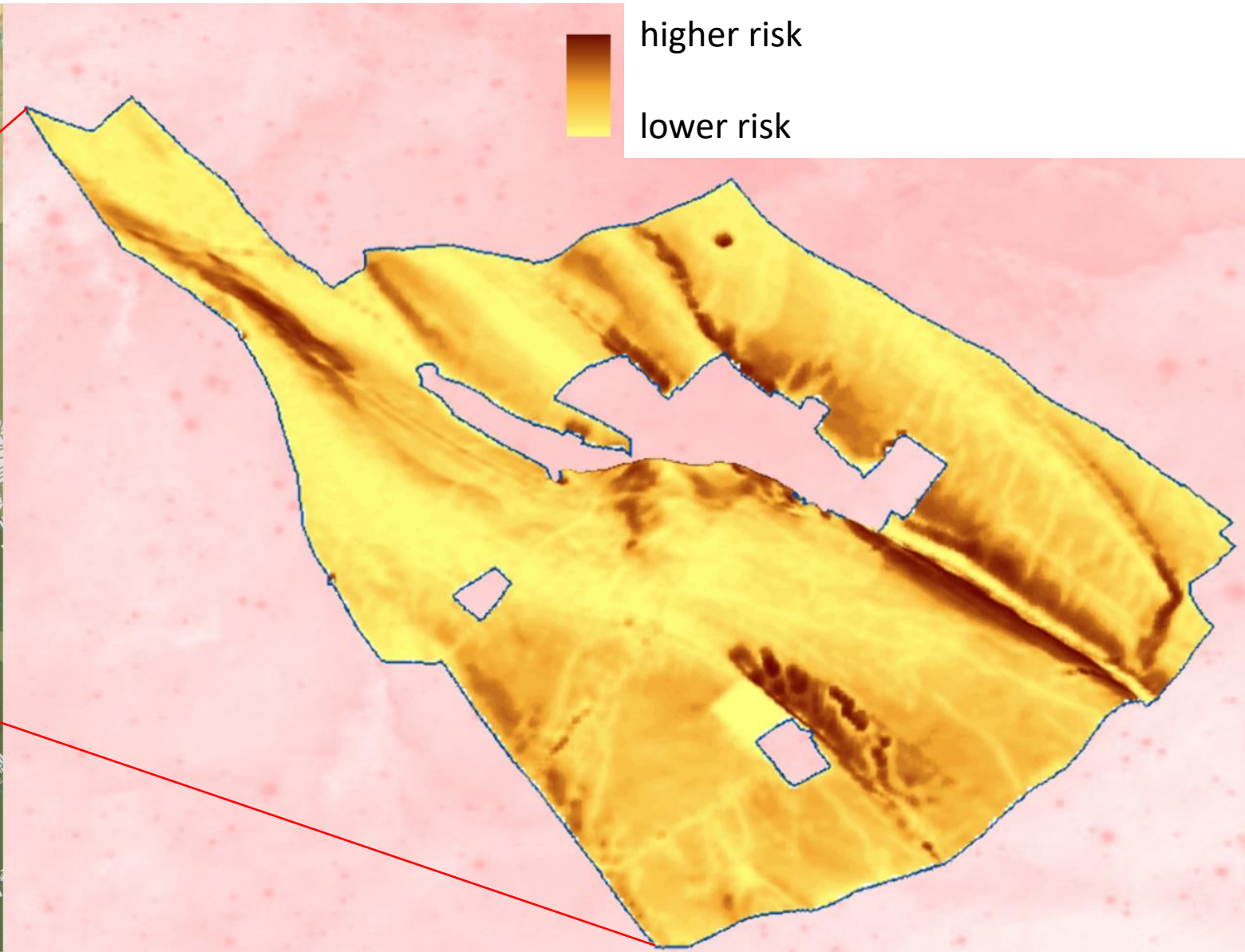
- There are six terms (factors) used in the USLE equation that are expressing quantitatively the effect of given parameters on soil loss.
- However, there are various different formulas used for calculating the respective factors and no “universal” method exists.
- Used mathematical expressions associated with calculation of given factors usually reflect differences in experimental design of given studies, used statistical methods or regional patterns of local/regional soil cover.
- For example, some works use silt, clay and organic matter contents, together with soil structure data as an input variables for K factor calculation, while other use also sand content and soil pH value as predictors of K factor.

Prediction maps expressing the risk of soil loss via water erosion

help to identify vulnerable areas
at regional level
and take appropriate measures



Prediction maps expressing the risk of soil loss via water erosion



identify vulnerable areas at local level

Wind erosion

probability of wind erosion increases when:

- soil moisture decreases (depends also on other soil properties)
- low/no **vegetation cover**
- stability of soil aggregates is low, insufficient **bonding between soil particles, loose soil structure**
- apart from climate, the wind erosion is affected by relief characteristics; more susceptible are the **plain – lowland areas**, unlike the landscape with more diverse topography

Prevention / stabilization measures

- **vegetation cover is the most cost-effective measure**; the use of fast-growing plants (trees), which have low demands for soil quality; for example, gullies in Slovakia were reforested with the black locust (*Robinia pseudoacacia*)
- use of **terraces** in landscape planning and architecture – relatively old technique that has been used in many parts of the world as simple and effective measure mitigating the risk of water erosion; it is not coincidence that terraces are wide-spread in the areas, where intense precipitation events / monsoons occurs (south-east Asia)
- the goal of prevention measures (terraces) is basically to **increases surface roughness** at local level, or in the other words, to create small “reservoirs” for the rainwater, and to slow down (minimize) the runoff
- in agricultural areas: ploughing along (**not across!**) the contours; it is good to include some parcels into large agricultural areas, which will not be ploughed at all – this fragmentation of agricultural land will increase surface roughness, reduce surface runoff and water erosion

Prevention / stabilization measures (old technique – terrace fields)



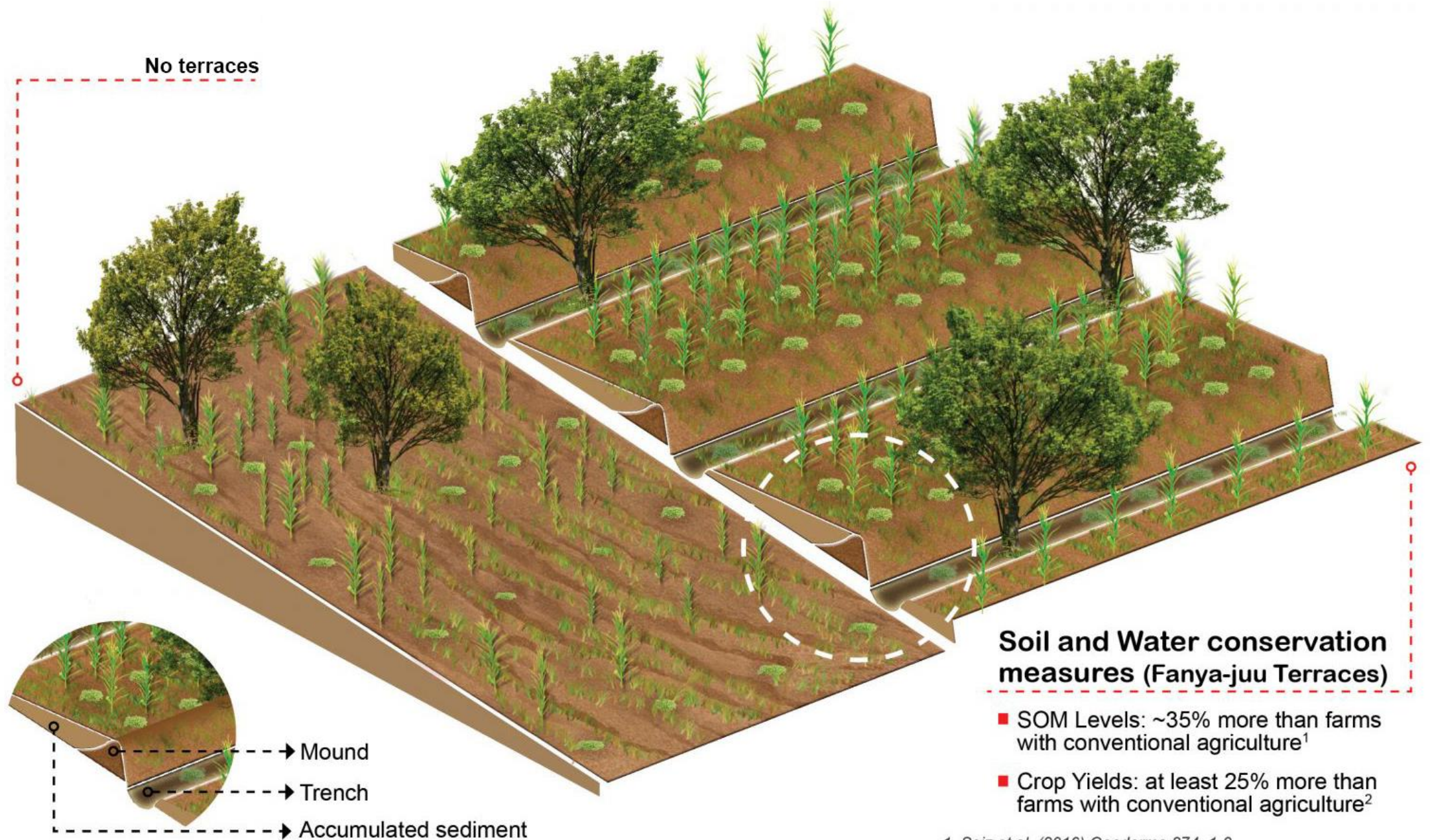
Prevention / stabilization measures (old technique – terrace fields)



Prevention / stabilization measures (old technique – terrace fields)



Prevention / stabilization measures (terrace fields → positive effects on soil organic matter content and crop yields)

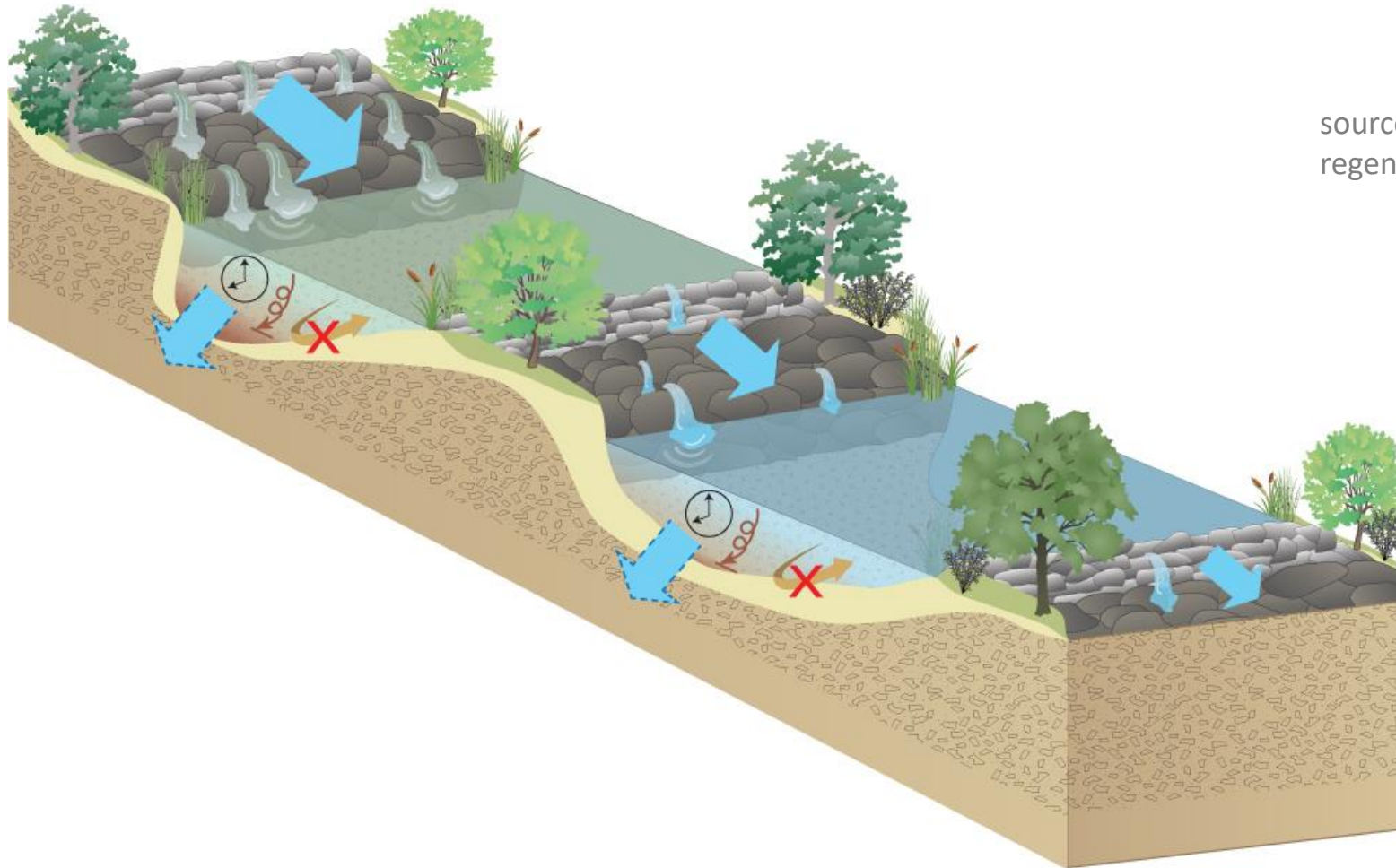


1. Saiz et al. (2016) *Geoderma* 274, 1-9

2. Ellis-Jones and Tengberg (2000) *Land Degrad. Dev.* 11, 19-36

Regenerative stormwater conveyance systems (RSC)

source: <https://ian.umces.edu/media-library/regenerative-stormwater-conveyance-systems-rsc/>



Reducing water quantity

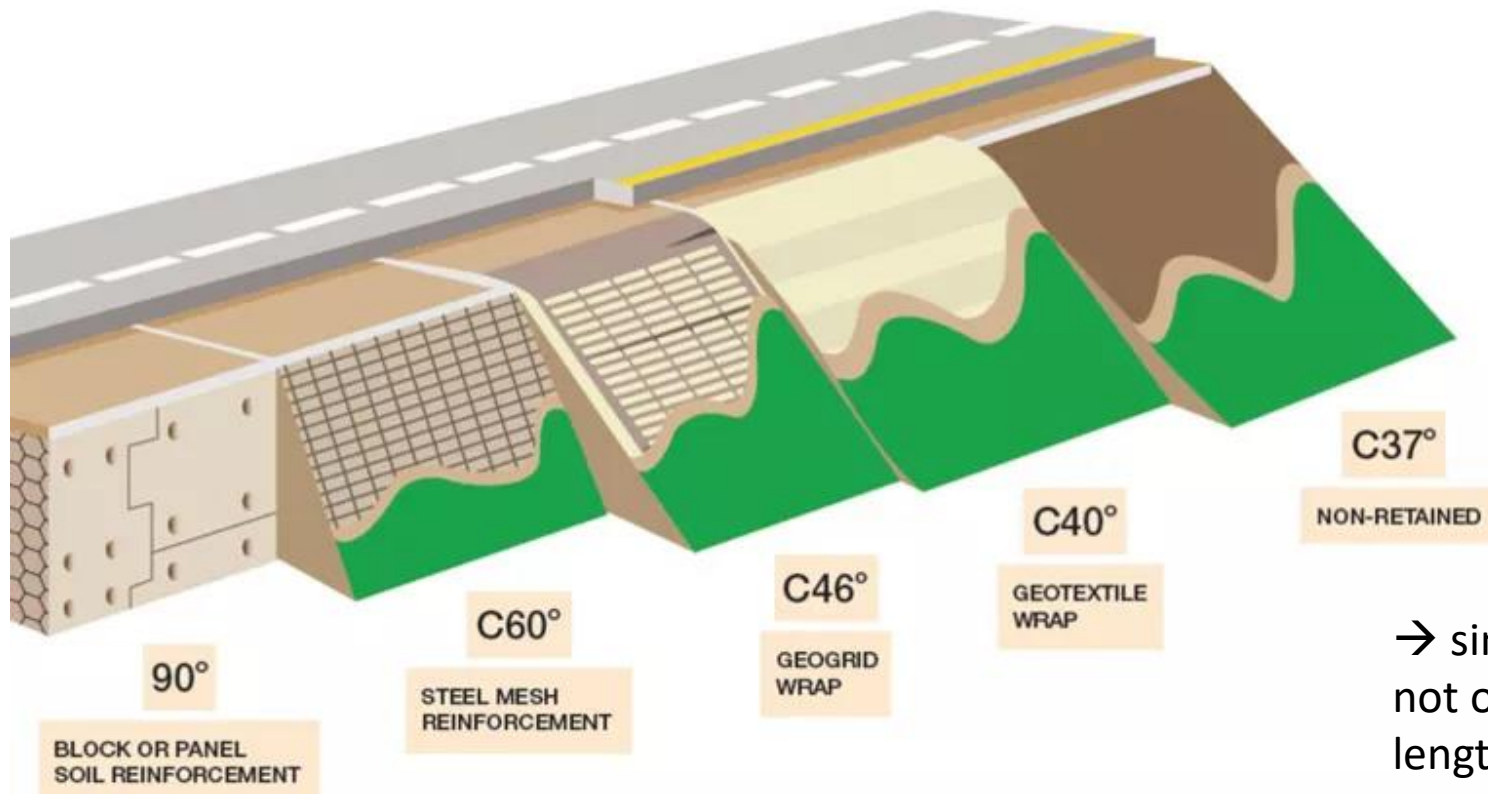
The structure of this system is effective at reducing stormwater volume , thereby preventing streambed erosion  and increasing groundwater recharge .

Improving water quality

With a reduced flow, stormwater is retained for a longer period , enabling pollutants, nutrients, and sediment to settle  and be biologically transformed. 

Prevention / stabilization measures (engineering approaches)

- using construction materials (geotextile, steel mesh/grid, concrete, shotcrete) to build a support system for slope stability



→ similarly as in the case of erosion modeling, not only slope (steepness) is important, but length of the slope and overall mass of soil body as well

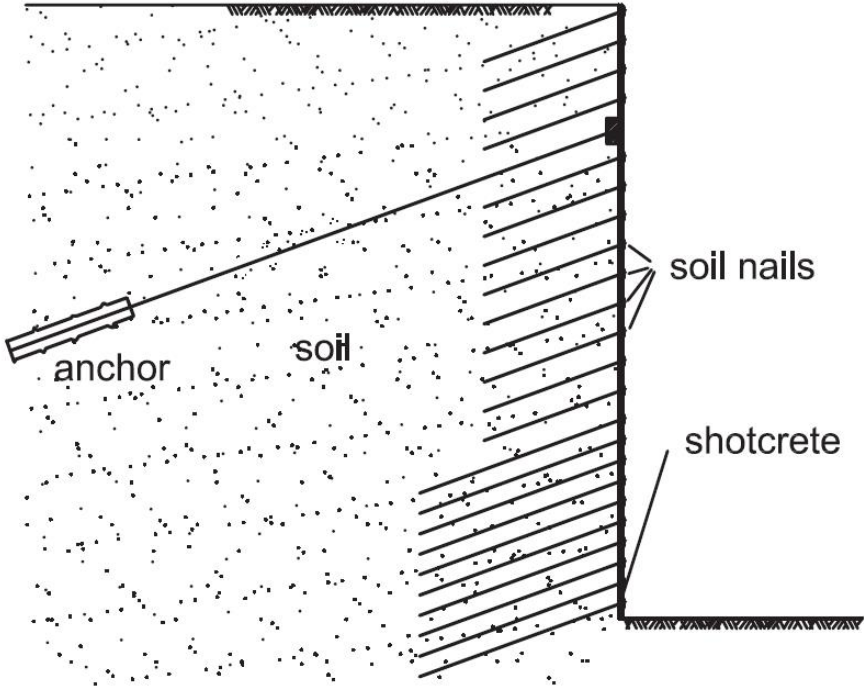
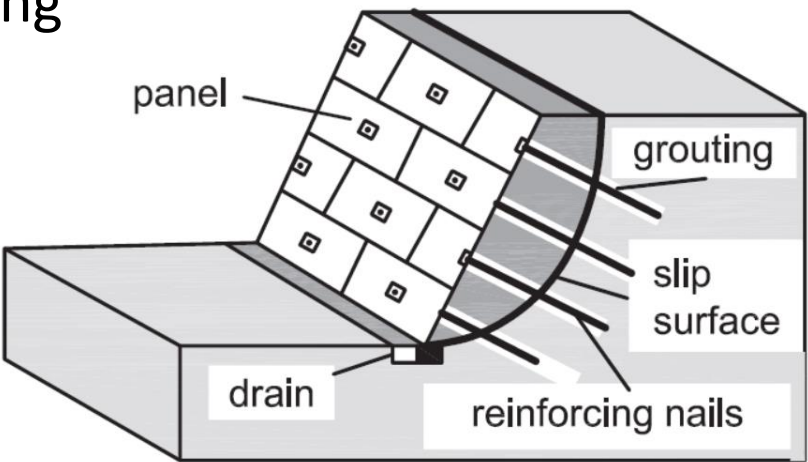
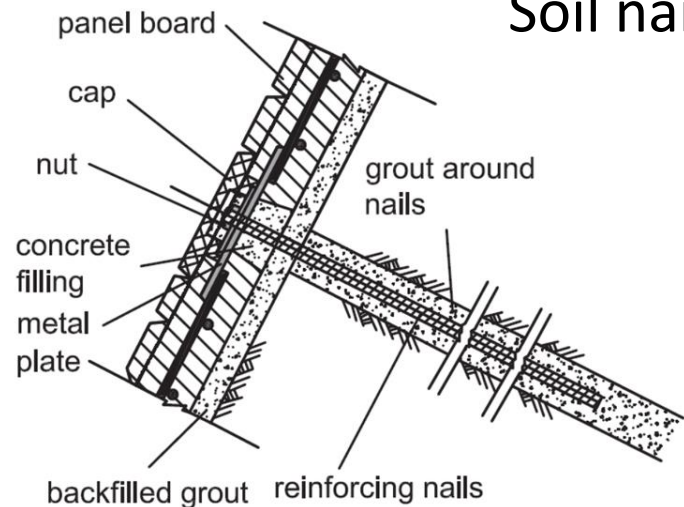
Prevention / stabilization measures (engineering approaches)

slope stabilization (Japan)



Prevention / stabilization measures (engineering approaches)

Soil nailing



Prevention / stabilization measures (engineering approaches)

soil nailing and placing the steel grids may be combined with shotcrete application

shotcrete: concrete applied by spraying; a mixture of sand/gravel particles and portland cement, conveyed by compressed air to the nozzle of a spray gun, where water is added.



Prevention / stabilization measures (engineering approaches)

shotcrete covered cliff
in New Zealand (Auckland) →

