Role of landscape structure in regulation of water and nutrient cycles

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The three challenges of water management

Water management faces only three, but critical challenges: seasonally there is too little or too much water, what impacts nature, numer of sectors and diverse human activities. When solving any of those problems, it is criticall to avoid approaches that can accelerate the others. The simultaneous positive effect can be achieved when using ecosystem properties as a management tool as proposed by UNESCO IHP Ecohydrology Programme*

Source | Pniewski 2016

* Zalewski M., Janauer GA., Jolánkai G. (1997). Ecohydrology. A new paradigm for the sustainable use of aquatic resources. Technical Document in Hydrology, IHP. Paris: UNESCO, 58 p.

Water cycle gaps – two types of challenges

Water shortage

long-term water imbalance = low water availability vs. level of water demand exceeding the supply capacity of the natural system reasons: low rainfall, high population density, intensive irrigation, industrial activities; water quality problem; assessment: Water Exploitation Index (WEI) used at different scales (i.e. national, river basin)

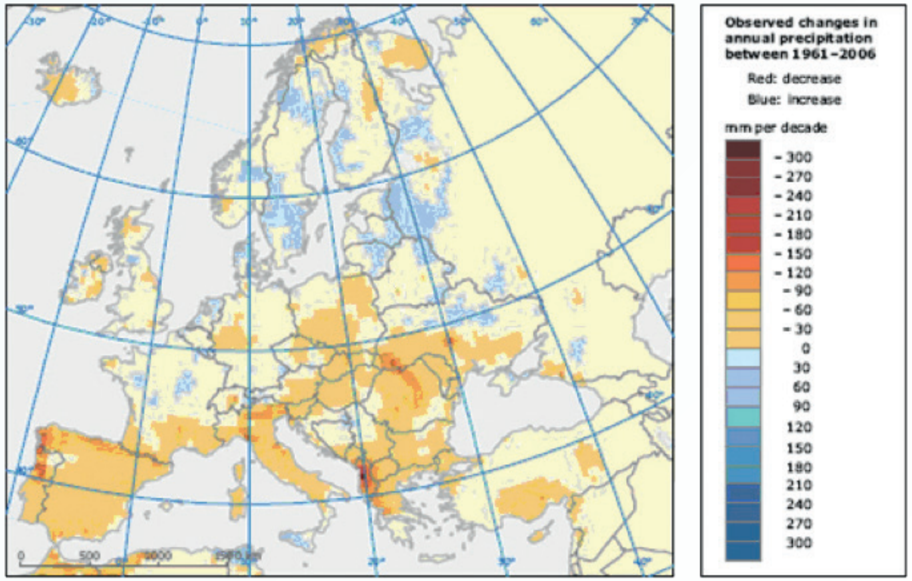
$$WEI = \frac{\text{average water demand}}{\text{long-term average resources}}$$

WEI identifies territories that have a high demand for water comparing to their resources

Drought

temporary decrease in average water availability the effects of droughts may be exacerbated when they occur in a region with low water resources or when management leads to an imbalance between water demand and the suppl capacity of the natural system;

Changes in annual precipitation between 1961 and 2006

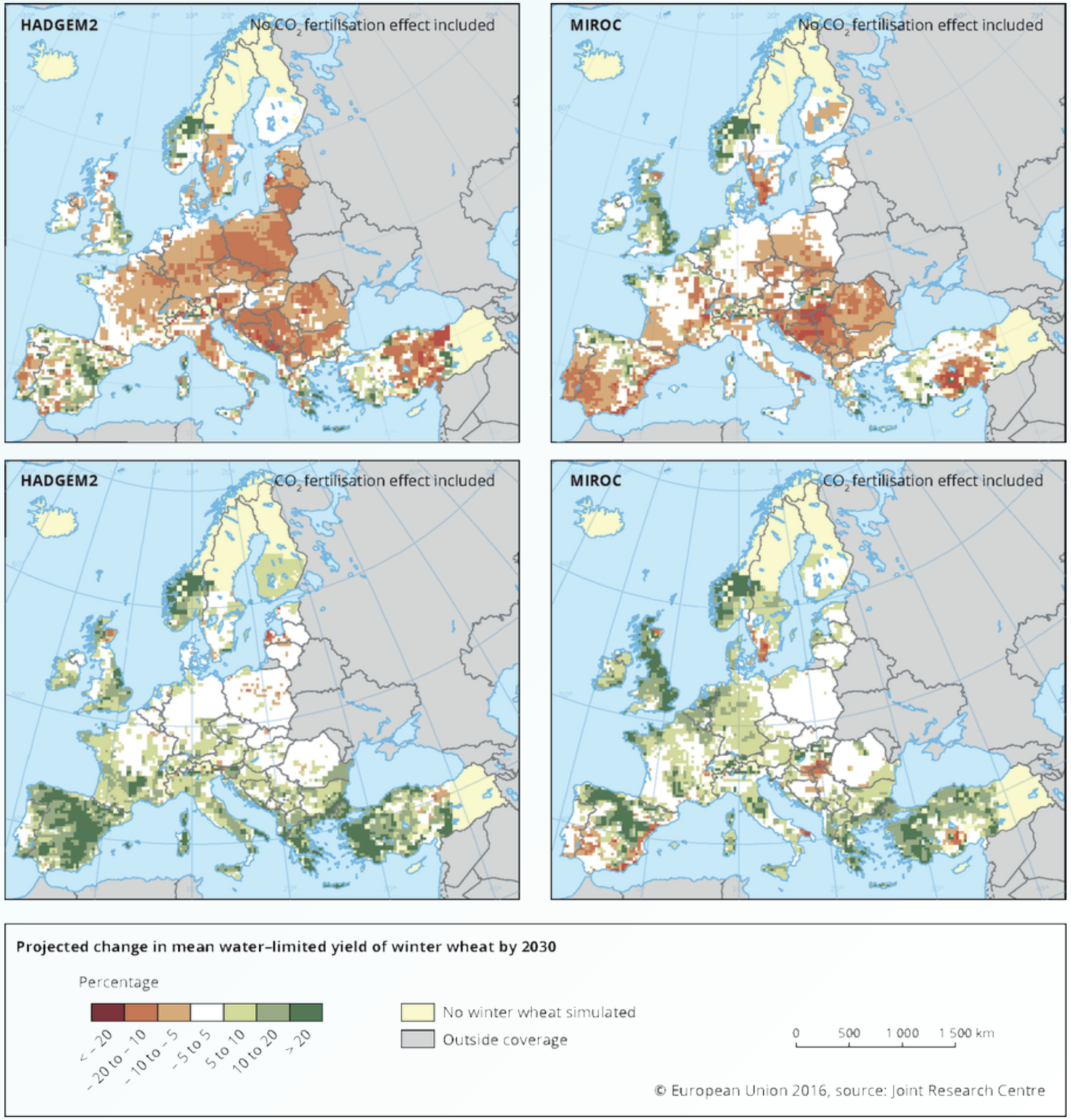


Source: The data come from two projects: ENSEMBLES (http://www.ensembles-eu.org) and ECA&D (http://eca.knmi.nl).

WATER QUALITY AND QUANTITY ARE DRIVEN BY CLIMATE AND LAND USE (IMPACTING LANDSCAPE STRUCTURE)

Effect of water cycle gaps: forecast for changes in crop yields

Expected change (%) in average winter wheat yield due to limited water resources; forecast up to 2030 by 4 scenarios. Two models predict significant drop in yields, when the CO2 fertilization effect is included, the situation is more optimistic for the southern Europe and becomes neutral for the central.



Projected changes in mean water-limited yield of winter wheat by 2030, in percentage. No CO2 fertilization effect included (A. HADGEM12 model, B. MIROC model), CO2 fertilization effect included (C. HADGEM12 model, D. MIROC model)

CO2 fertilization effect | https://en.wikipedia.org/wiki/CO2_fertilization_effect

Climate changes superimposed by land use

Water quantity / quality issues are influenced not only by climate changes, but also by the way people manage the land. In rural areas subsidies offered by CAP for land cultivation seem to competitively defeat agri-environmental schemes. Organic soils (peat, bogs, swamps, marshes) easily mineralize when they are used intensely as arable grounds, losing productivity, but also ability to retain water, to trap chemicals, and to provide habitats.

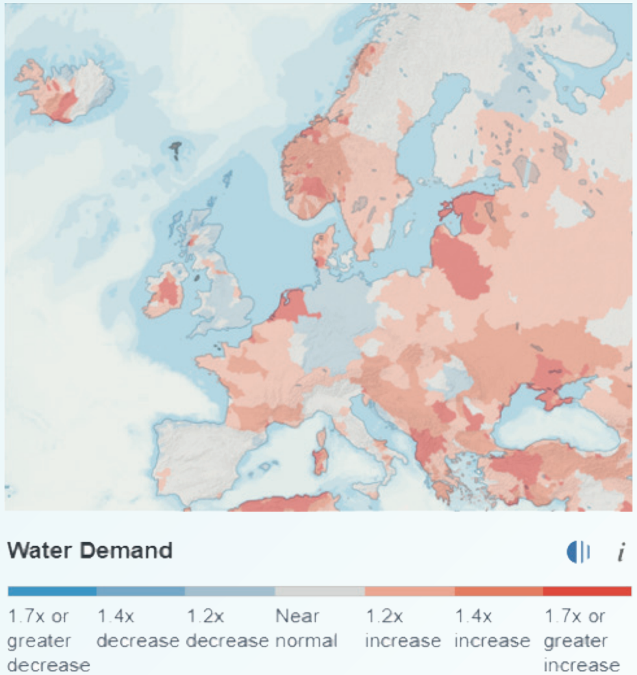
Photos | Andrzejewski

The signs of decay of organic soil
– fast mineralisation results in conversion
of fertile soil into sandy fallow

Pictures show good (upper) – extensive and close to natural
and bad (lower) – land is intensely cultivated to the river bank,
land use practices within floodplains and wetlands.

Climate changes superimposed by land use

Water demand and related water stress projections by 2030 as a change from the baseline, under scenario „business as usual”. With unchange water use schemes almost whole Europe is to increase water demand around 1.2 to 1.4 times, what may eventually lead to intensified water stress, and endanger small / lansdcape retention: ponds, wetlands and creeks.



Water demand (A) and water Stress (B) by 2030:
range bewteen greater decrease – near normal – greater increase

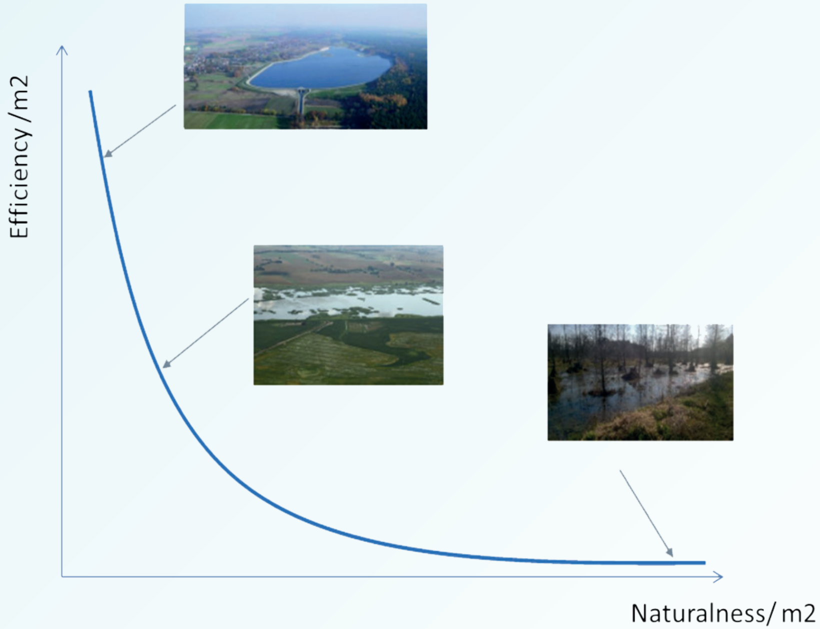
Photos | Andrzejewski

The picture illustrates drying marshland of Central Poland

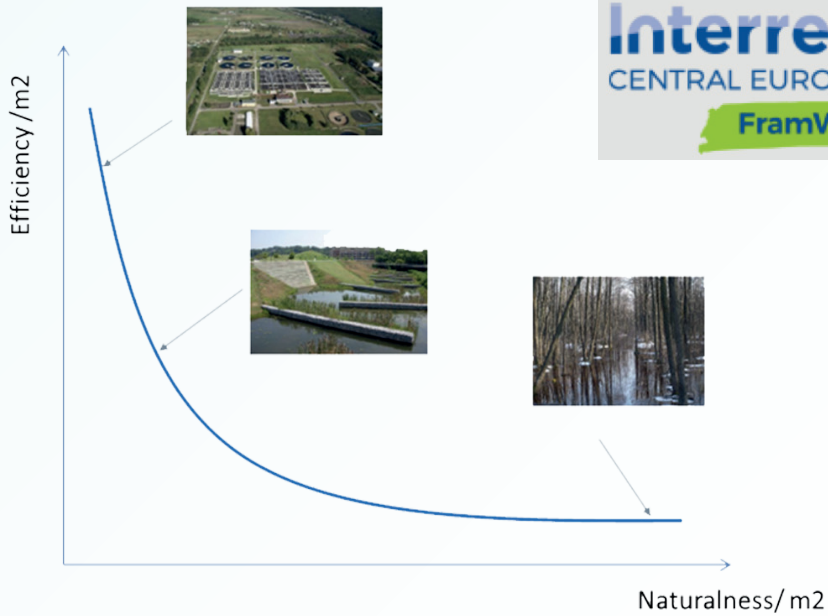
SOURCE | © World Resources Institute – Aqueduct

Role of ecosystems in water and nutrient cycling

Both water retention and purification functions are performed by ecosystems at landscape level, however they are often substituted by technical solutions. Water storage efficiency is estimable and high for reservoir, however this is an artificial way of retaining water and reservoirs perform limited functions comparing to natural watercourses and wetlands, and impose maintenance costs. Similarly, water purification efficiency is high in water treatment plant, but the same function can be performed at no costs by riparian zones and wetlands..



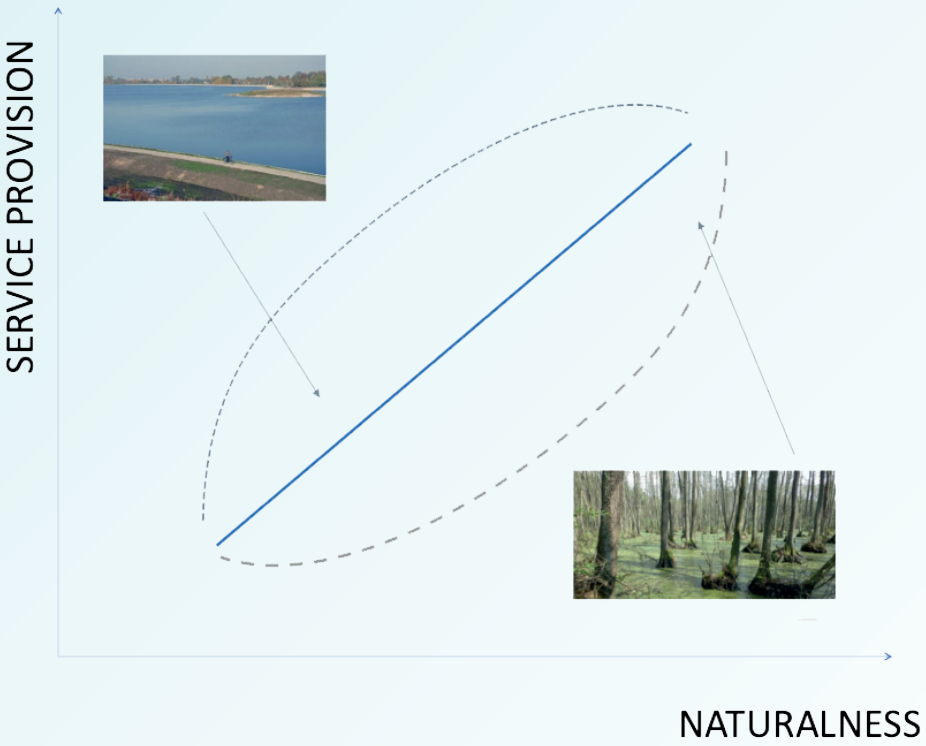
Water storage: naturalness/m2 vs Efficiency/m2



Water Purification: Naturalness/m2 vs Efficeincy/m2

SOURCE | Okruszko, 2019

Role of ecosystems in water and nutrient cycling



Natural systems usually cannot compete with artificial ones regarding efficiency of performing one particular function (e.g. water storage in reservoirs), however they are unbeatable in terms of number of services delivered simultaneously, with particular emphasis on regulatory and supporting ones.

For example wetlands not only store water, but also efficiently accumulate it during rainy period, contribute to CO2 trapping, biomass production, habitat provision, biodiversity protection, education and water purification.

Reservoirs store water very efficiently however they don't deliver as many services as wetlands and they generate problems, e.g. decline of river biodiversity, accumulation of pollution and sediments, maintenance costs.

Interreg CENTRAL EUROPE European Union European Regional Development Fund FramWat

SOURCE | Okruszko, 2019

Landscape retention

The components of landscape water retention indicate direction of the use of landscape planning tools. Each of the equation elements can be incorporated solely or jointly into water management practices, e.g. by protection or re-meandering the rivers we can increase channel retention, by improving soil conditio and increasing organic content we can increase soil retention, etc.

LANDSCAPE RETENTION Rc

Rc =Ri +Rpn +Rw +Rrz +Rd +Rgl +Rgr +Rbo

Ri **INTERCEPTION** (storage of water on the surface of plants)

Rpn **RETENTION OF IMPERMEABLE SURFACES** (water stored on surfaces that prevent infiltration)

Rw **RETENTION OF STAGNANT WATERS** (lakes, ponds, reservoirs, marshes, wetlands, peatbogs)

Rrz **RETENTION OF RIVERS AND CHANNELS**

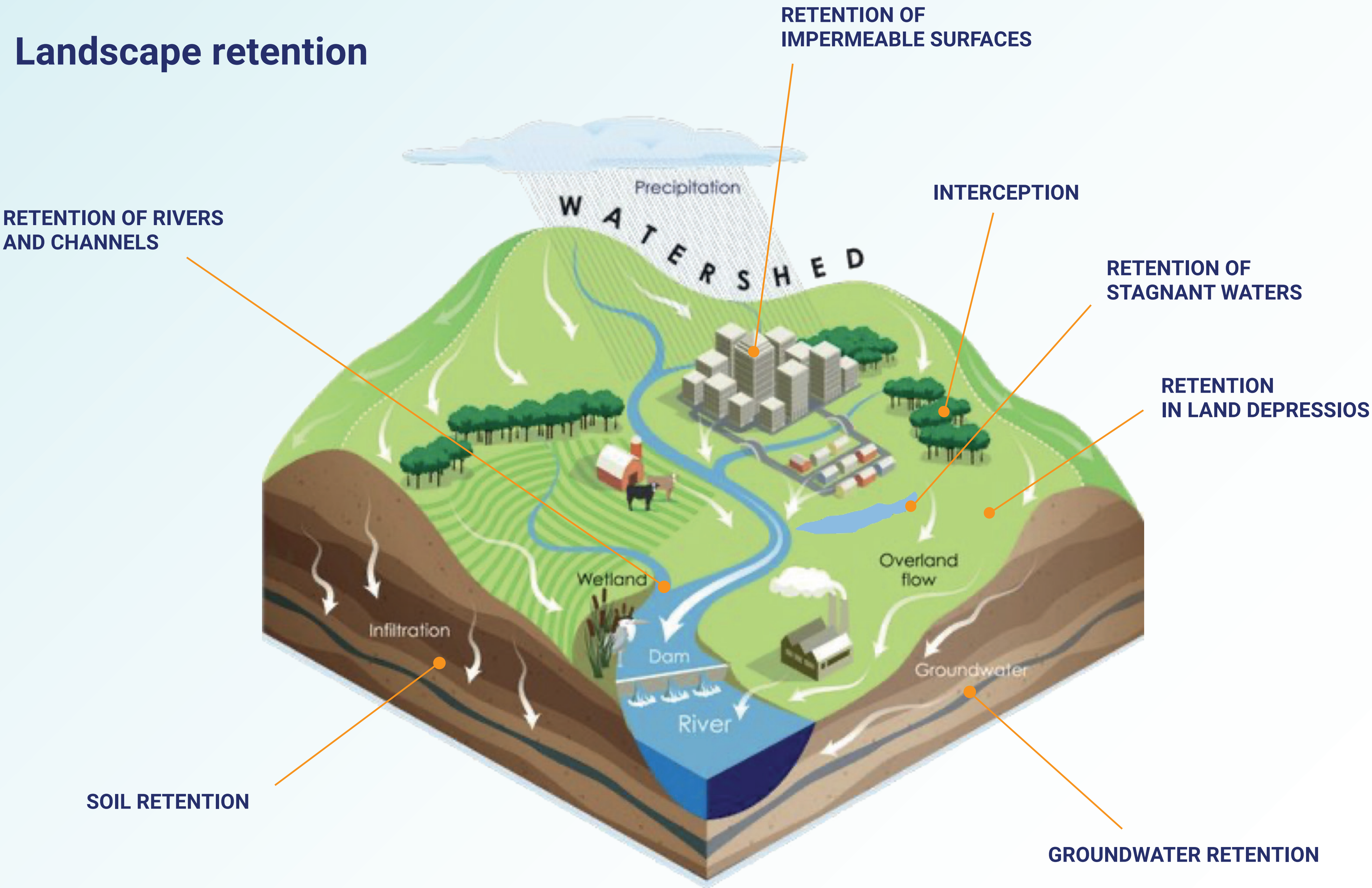
Rd **RETENTION IN LAND DEPRESSIOS**

Rgl **SOIL RETENTION**

Rgr **GROUNDWATER RETENTION**

Rbo **WATER RETENTION IN INTERNAL DRAINAGE SYSTEMS** (not in hydraulic contact with the river basin network)

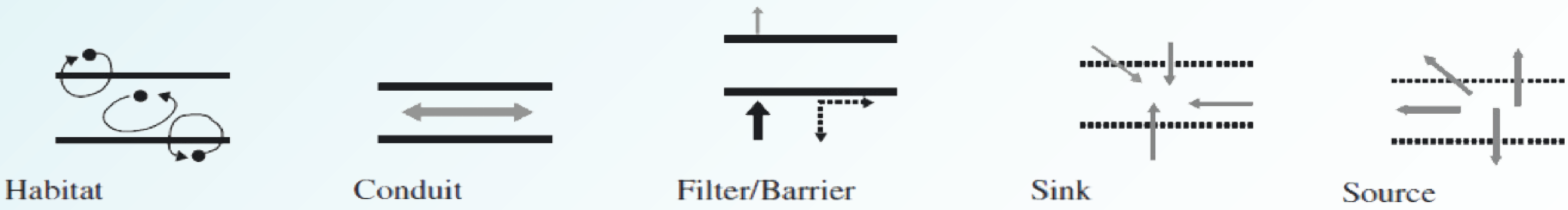
Landscape retention



Role of landscape elements

Understanding of the role of landscape elements helps to establish sustainable landscape planning: planning which preserves landscape elements with their critical functions supporting water management.

Ecological funkction of shelterbelts (Mize et al. 2008)



Habitat:
Provides resources
(e.g. food, shelter,
reproductive cover)
to suport an organism's needs

Conduit:
Convey energy, water,
nutrient, seeds, oragnisms
and other elements within
the linear elements

Filter/Barrier:
Intercepts wind,
wind-blown particles,
surface and subsurface
water, water-carried materials
(e.g. nutrients, pesticides,
sediments), genes, and animals

Sink:
Receives and retains
objects and substances
tah originate in the adjacent
matrix of land

Source:
Releases objects
and substances
into the adjacent
matrix of land

SOURCE |https://digitalcommons.unl.edu/usdafsfacpub/40

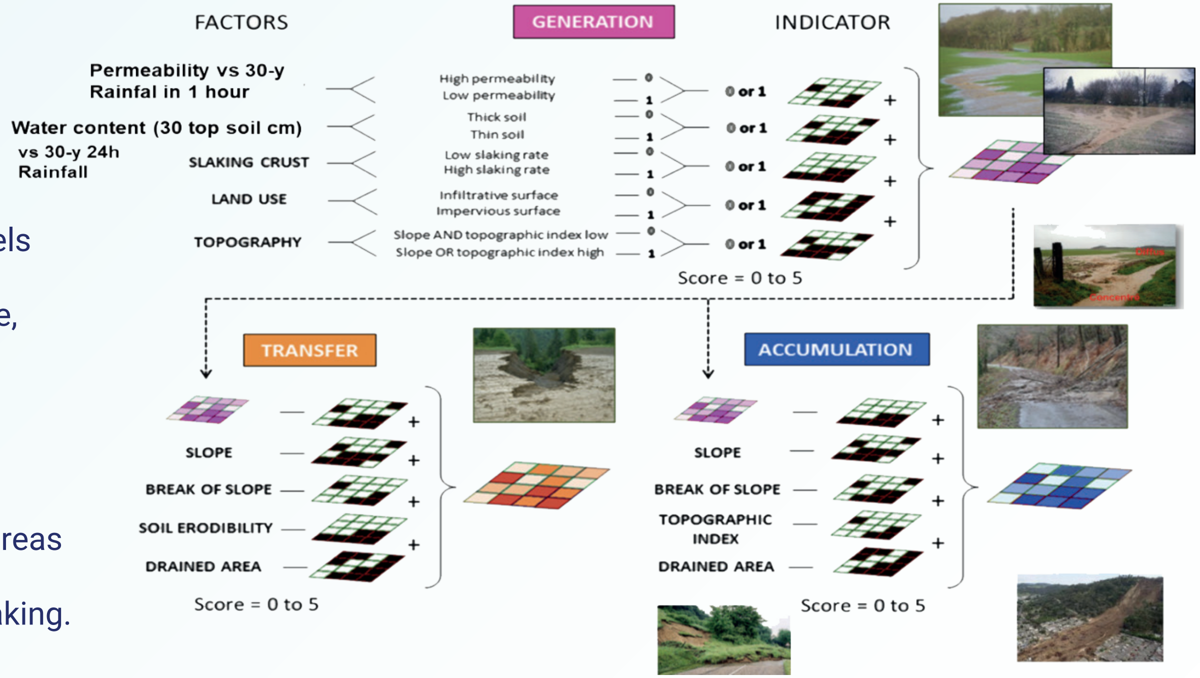
Correct size of soil aggregates reduces evaporation

MODELLING FOR IDENTIFICATION OF WATER SINKS, SOURCES, TRANSFER ZONES AND BARRIERS, E.G. IRIP MODEL BY INRAE

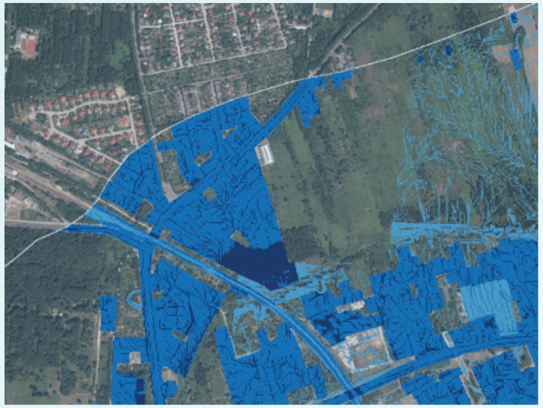
To understand which landscape elements must be preserved or restored, it is critical to identify areas contributing to run off generation, transfer and accumulation.

IRIP model - Indicator of Intense Pluvial Runoff is one of models helping to understand those processes based on terrain shape, soil types and land use.

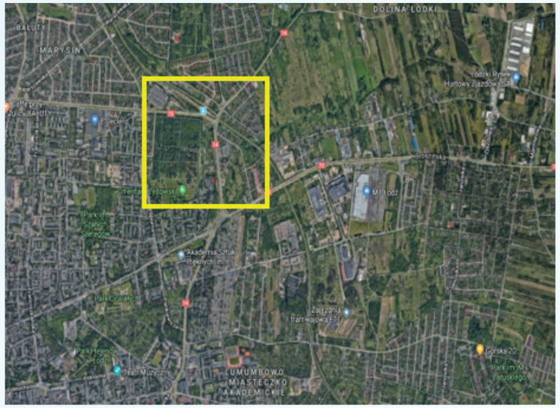
It is important to trap water and chemical compounds in the areas of runoff generation to prevent water loss and e.g. nutrient leaking. Areas of water accumulation should be equipped with systems supporting nutrient trapping and water storage, often wetlands are located in such places indicating areas that should be excluded from development.



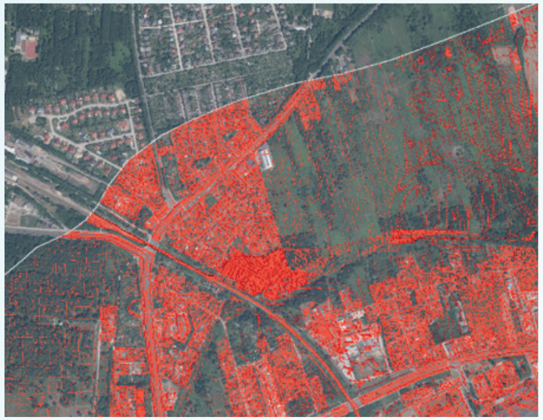
MODELLING, E.G. IRIP MODEL FOR SUBURBAN AREAS OF THE CITY OF ŁÓDŹ



Intense runoff production areas



Focus area



Accumulation areas

Transfer areas

Concluding map with all layers

SOURCE | Breil 2020

Landscape level measures

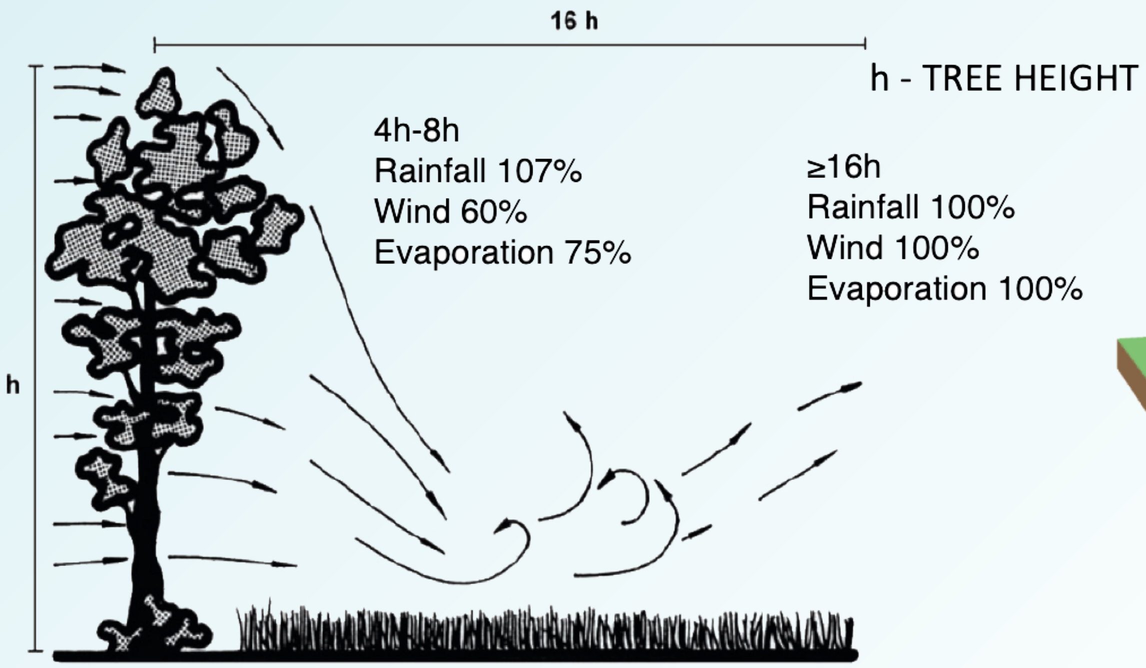
There is a numer of measures applicable at landscape level that shape water and nutrient cycling in runoff generation and accumulation sites. The most efficient ones are the ones selected below.

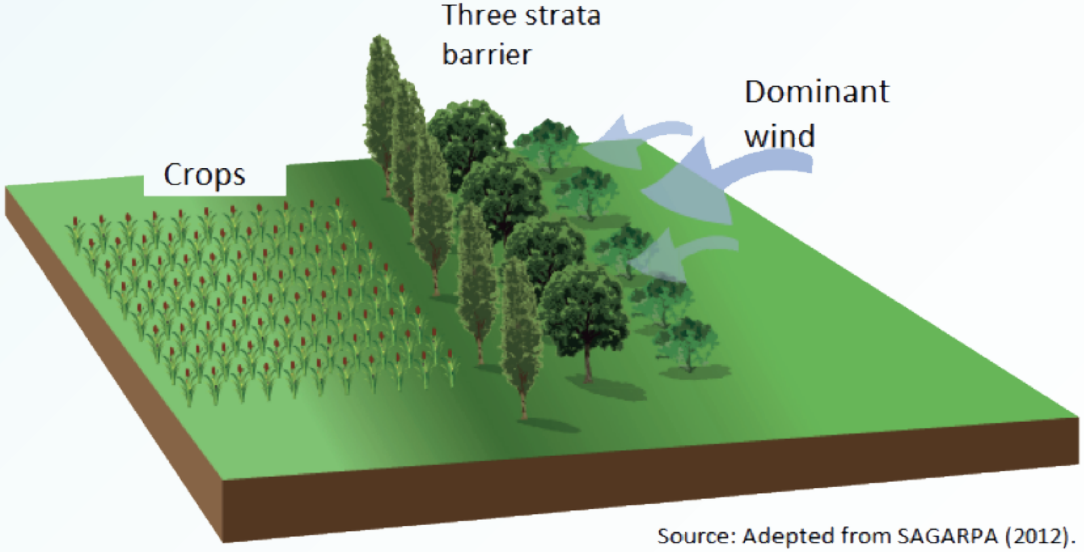
- Afforestation of agricultural lands (poorly permeable soils, hummocky area, presence of snow melting floods)
- Mid-field afforestation (intensive agriculture, lack of forests, problems resulting from eolian erosion)
- Buffer zones along water courses and reservoirs lands (poorly permeable soils, hummocky area)
- Construction of micro reservoirs on ditches
- Water course restoration (meandering)
- Swamps restoration (peatlands)
- Small ponds (restoration)
- Old meanders/side reservoirs on rivers (retaining water during high spring flow)

Name of the indicator	Impact on water resources			Impact on			Threats
	Surface water	Soil retention	Groundwater	Landscape	Biodiversity	Water quality	
Afforestation of agricultural lands (poorly permeable soils, hummocky area, presence of snow melting floods)	++	+/-	+/-	+++	+++	++	Disappearance of certain plants (weeds)
Afforestation of agricultural lands (permeable soils – sands, presence of snow melting floods)	+	+/-	+/-	++	+++	++	Decrease of alimentation of groundwater aquifers
Mid-field afforestation (intensive agriculture, lack of forests, problems resulting from eolian erosion)	+	++	+	+++	+++	+	Implementation of foreign species
Agrotechnics (soil structure improvement) – poorly permeable soils	++	+++	++	+	+	++	Excessive intensification of agriculture
Agrotechnics (soil structure improvement) – permeable soils	+++	+++	++	+	+	++	Decrease of alimentation of groundwater
Agrotechnics-field water harvesting (small dikes around field edges)	+++	+++	+++	+/-	++	+++	Large impact on the loss of deposits on the floodplain valley
Buffer zones along water courses and reservoirs lands (poorly permeable soils, hummocky area)	+	+	+	++	++	+++	Decrease of the area of grasslands and arable lands
Regulated outflow from drainage systems	+	++	+++	+	+	+++	Excessive humidity of arable lands, soil degradation (reduction processes)
Active water management on a drainage system (river valleys)	+++	+++	+	+	+	+	Intensification of agriculture
Construction of micro reservoirs on ditches	+++	++	++	++	+++	++	Excessive humidity of arable lands
Infiltration reservoirs and ditches	+	+	+++	+	+	++	Pollution of groundwater
Dry reservoirs/flood polders (river valleys used for agricultural purposes	+++	++	+	+	++	+	Periodic destruction of crops yields, excessive humidity/drying
Construction of reservoirs on outflows from drainage systems	++	+	+	++	++	+++	Loss of the area for agricultural production
Old meanders/side reservoirs on rivers (retaining water during high spring flow)	++	+	++	++	++	+	--
Construction of small reservoirs on rivers (dammed reservoirs)	+++	++	++	+	++	++	Destruction of valuable ecosystem, problems with fish migration
Dug ponds in local terrain denivelations	+	++	+	+	++	+	Destruction of valuable ecosystems
Small ponds (restoration)	++	++	+	++	+++	+++	Conversion of the ecosystem into less valuable
Water course restoration (meandering)	+++	++	+	+++	+++	++	Flooding of agricultural lands
Swamps restoration (peatlands)	+++	+++	++	+++	+++	++	Excessive limitation of water courses alimentation
Anti-erosion measures (various)	++	+	++	++	++	++	Changes in ecosystems

Scale: +++ meaningful impact, ++ medium impact, + small impact, +/– negative or no impact

Landscape measures: mid-field afforestation





Source: Adepted from SAGARPA (2012).

The way mid-field afforestation modifies climate of the nearby areas: comparison between the zone distant up to 8x height of trees, and outside the impact zone. In general trees decrease water loss by reduction of wind speed and evapotranspiration, they also increase moisture what affects rainfall and allow snow cover to stay longer.

SOURCE | Kędziora 2004

Landscape measures

Diversification of landscape (e.g. by implementation of a number of measures) has particularly positive effect on water and chemical cycles. Below data show exemplary rural catchment in Western Poland. Independently of the season mosaic landscape prevent water loss and nutrient leaking, hence lower risk of droughts and water pollution. Additionally they maintain biodiversity at the same level as national parks securing natural regulation of pests, diseases and invasive species.

Season	Rainfall (mm)	Unified landscape			Mosaic landscape		
		Water outflow	$N\text{-}NO_3^-$	$N\text{-}NH_4^+$	Water outflow	$N\text{-}NO_3^-$	$N\text{-}NH_4^+$
Winter (Nov.-April)	220.7	60.8	12.3	3.0	56.8	0.90	0.95
Summer (May – Oct.)	292.9	41.2	4.0	1.1	13.4	0.05	0.25
Year	513.6	102.0	16.3	4.1	70.2	0.95	1.20

Outflow [mm], nutrient retention [g/m2 yr]

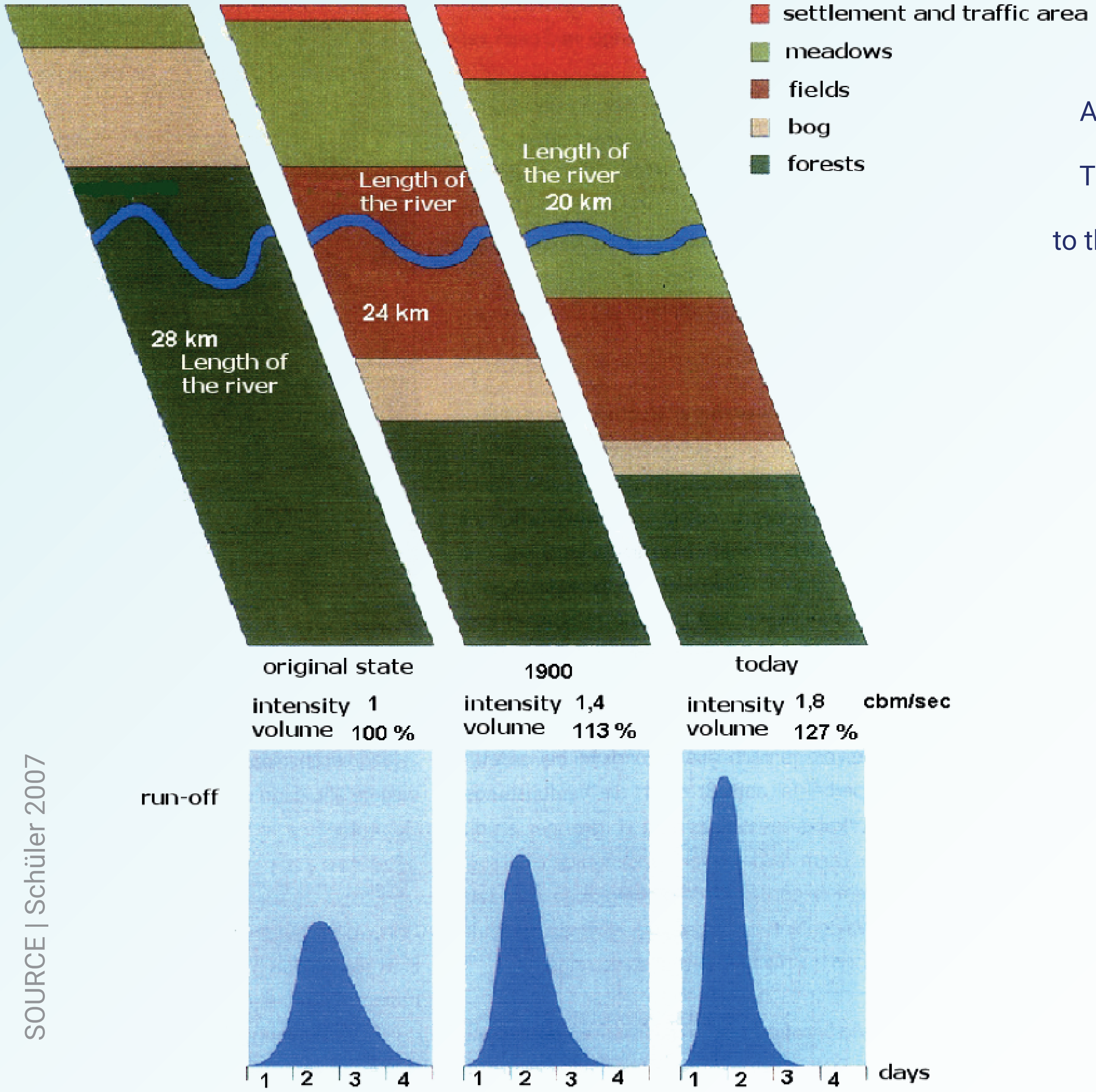
SOURCE | Bartoszewicz, 1994

Spatial planning does matter – Nahe catchment, Germany

Another example of influence of landscape structure on runoff.

The more transformed is river valley, the more water is lost due to the increased outflow. This results in peak flows after rainfalls and generates flood risk to areas situated downstream.

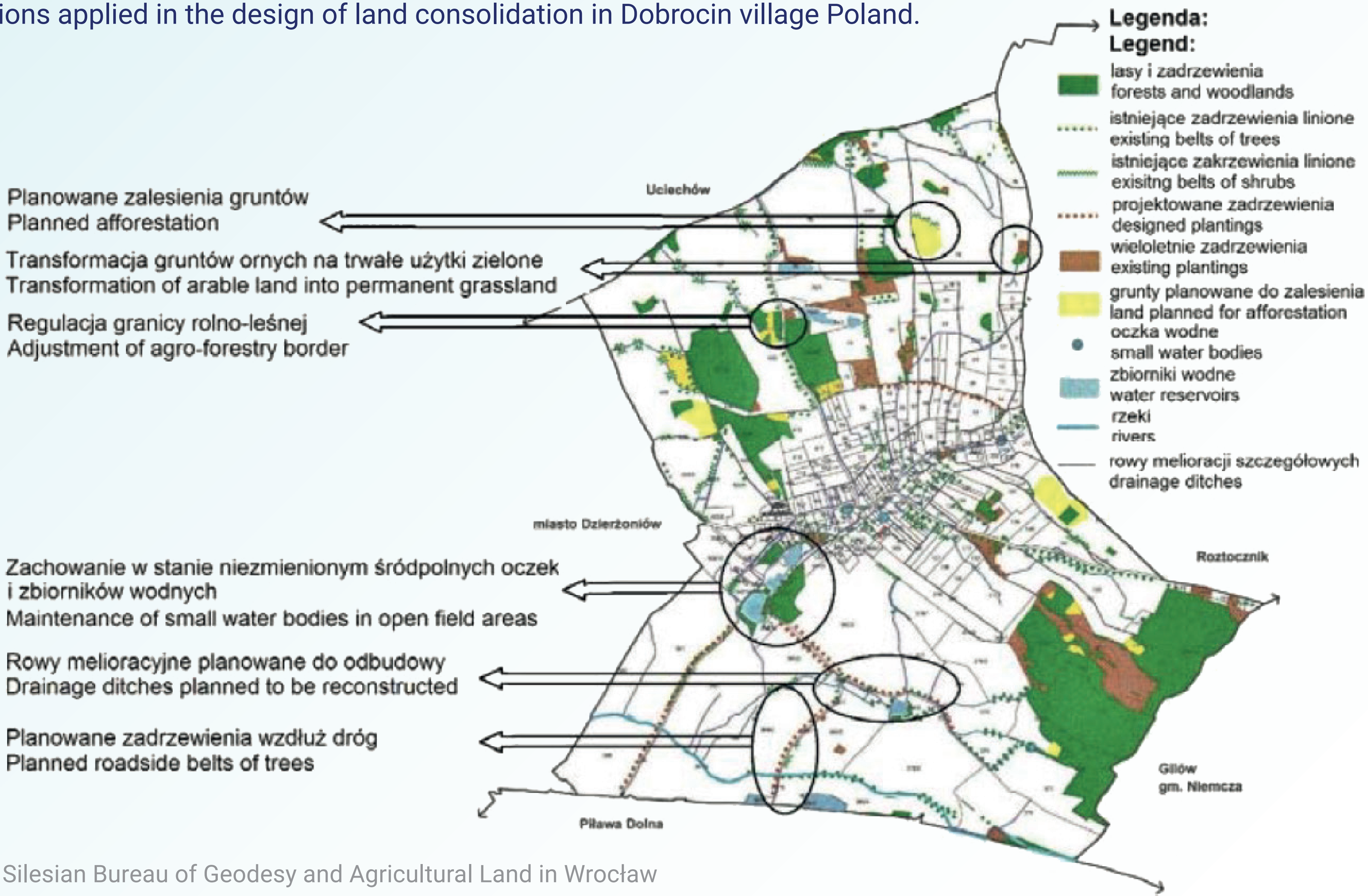
Leaving natural vegetation stinulates water retention on-site.



SOURCE | Schüler 2007

Example of water-focused spatial planning from one of polish communes

Selected solutions applied in the design of land consolidation in Dobrocin village Poland.



SOURCE | Lower Silesian Bureau of Geodesy and Agricultural Land in Wrocław

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