University of Kurdistan
Faculty of Natural Resources
Dept. of Rangeland and Watershed Management

Ecohydrology

Kamran Chapi

Definition of Ecohydrology

Ecohydrology is a scientific concept applied to environmental problem-solving. It quantifies and explains the relationships between hydrological processes and biotic dynamics at a catchment scale.

The concept is based upon the assumption that sustainable development of water resources is dependent on the ability to restore and maintain evolutionarily established processes of water and nutrient circulation and energy flows at the basin scale.

Definition of Ecohydrology

This depends on an in-depth understanding of a whole range of processes involved that have a two-dimensional character:

1. **temporal:** spanning a time frame from the past to the present with due consideration of future global change scenarios; and
2. **spatial:** understanding the dynamic role of aquatic and terrestrial biota over a range of scales from the molecular- to the basin-scale.

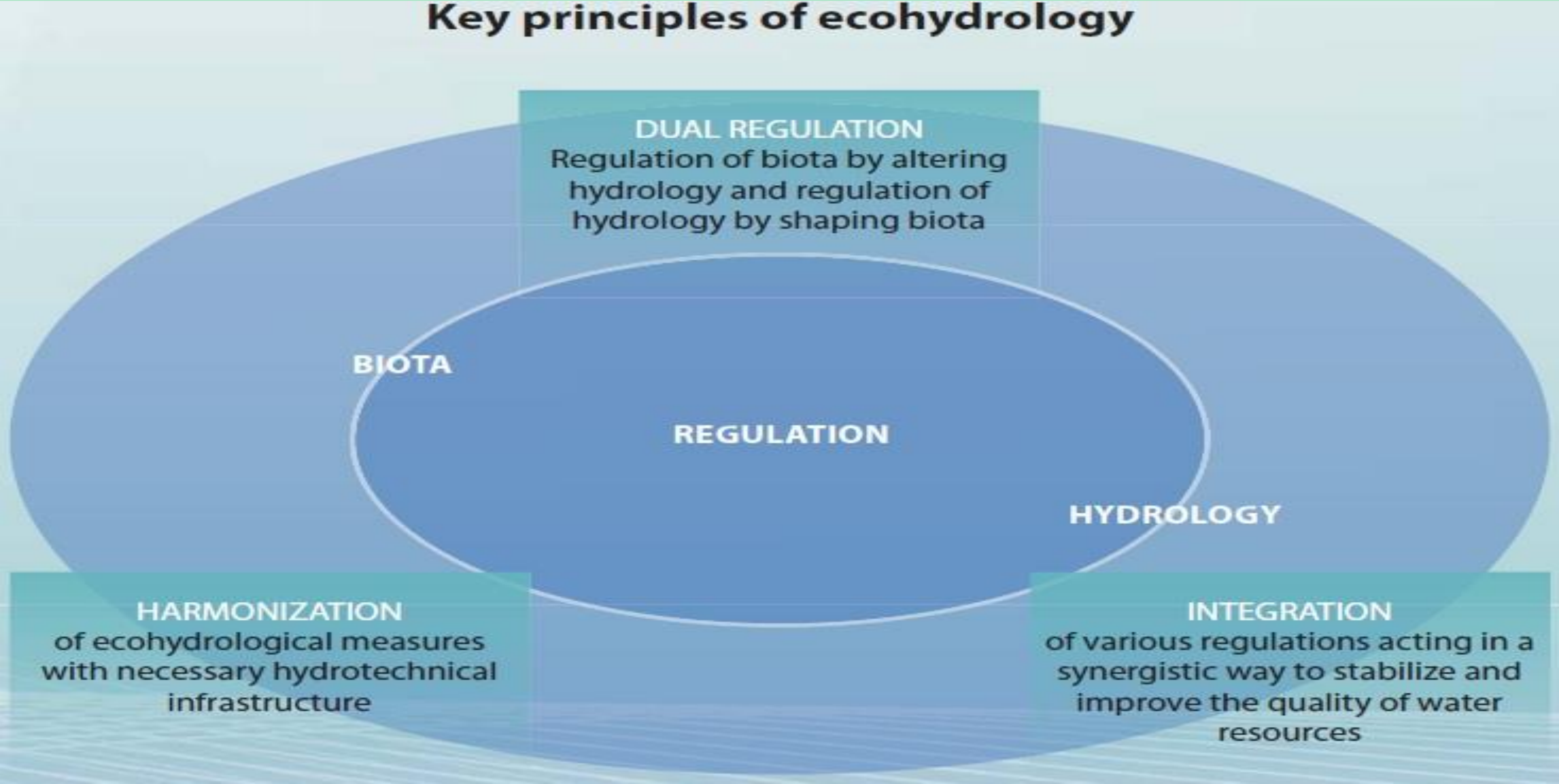
Both dimensions should serve as a reference system for enhancing the buffering capacity of ecosystems against human impacts by using ecosystem properties as a management tool. This, in turn, depends on the development, dissemination, and implementation of interdisciplinary principles and knowledge based on recent advances in environmental science.

Ecohydrology Assumptions

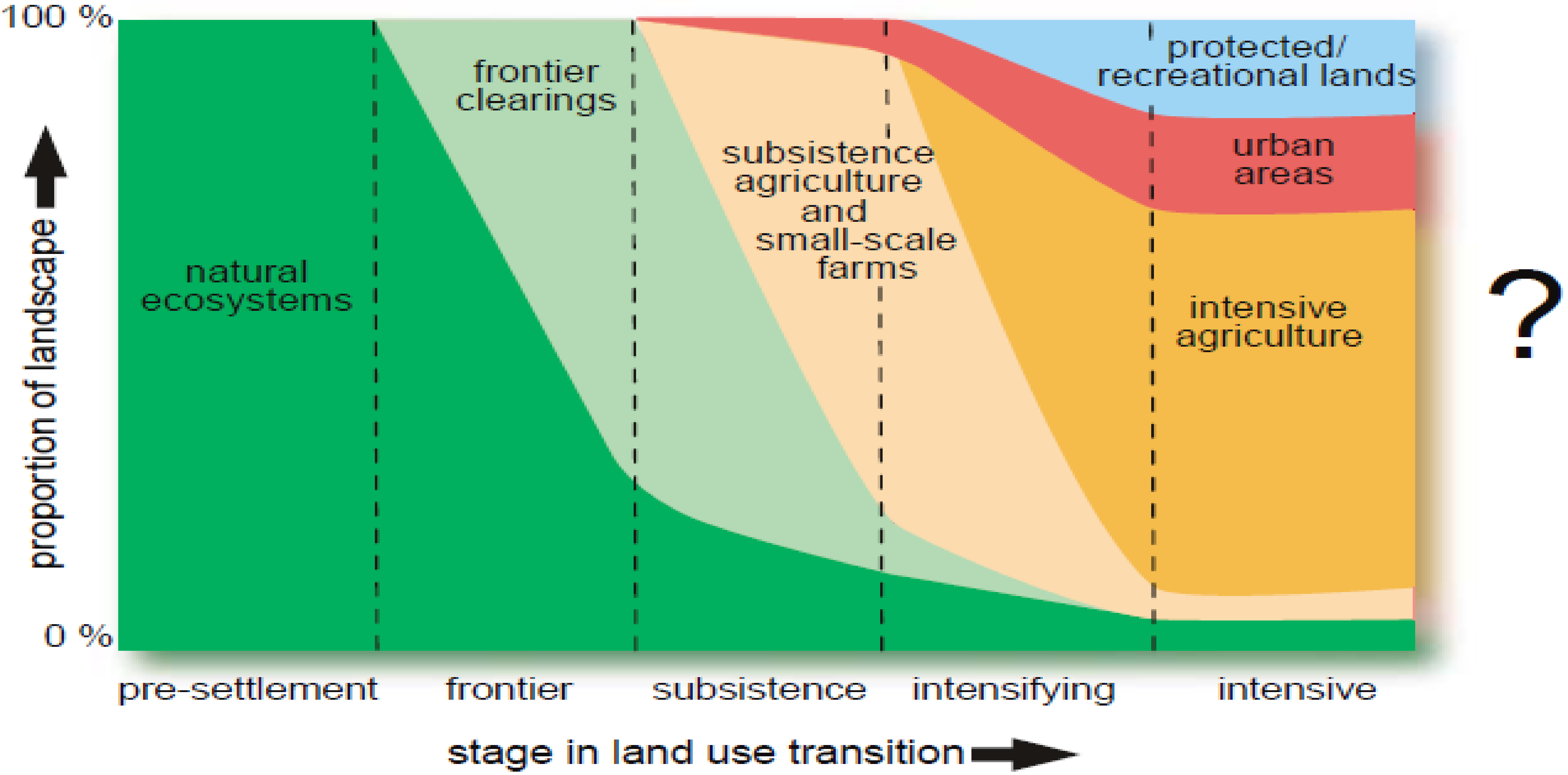
The ecohydrology paradigm, which is based on functional relationships between hydrology and biota can be expressed in three key assumptions:

1. **REGULATION** of hydrology by shaping biota and, vice versa, regulation of biota by altering hydrology.
2. **INTEGRATION** - at the basin scale various types of regulations act in a synergistic way to improve and stabilize the quality of water resources.
3. **HARMONIZATION** of ecohydrological measures with necessary hydrotechnical solutions (e.g., dams, sewage treatment plants, levees at urbanized areas, etc.)

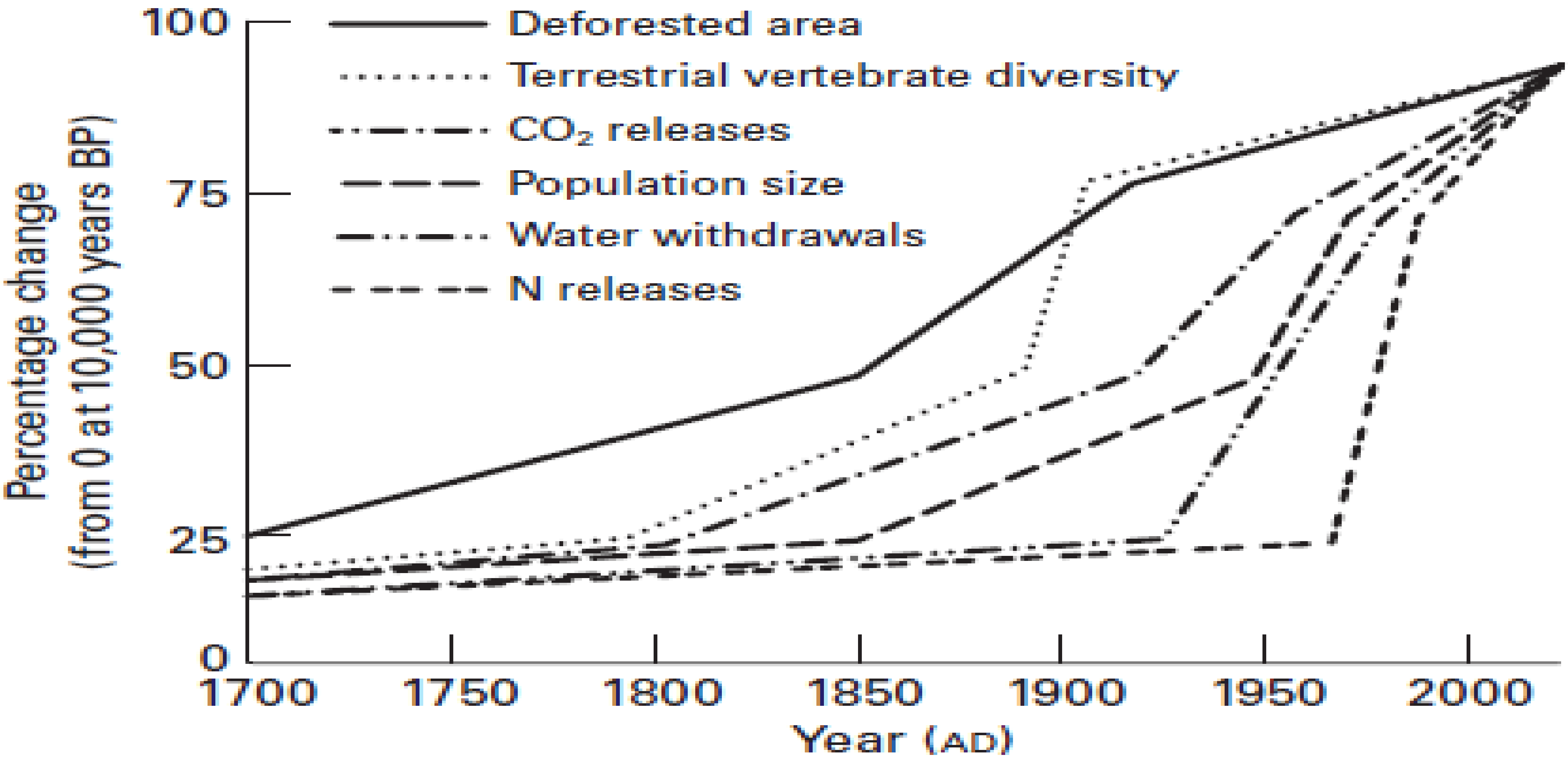
Ecohydrology Principles



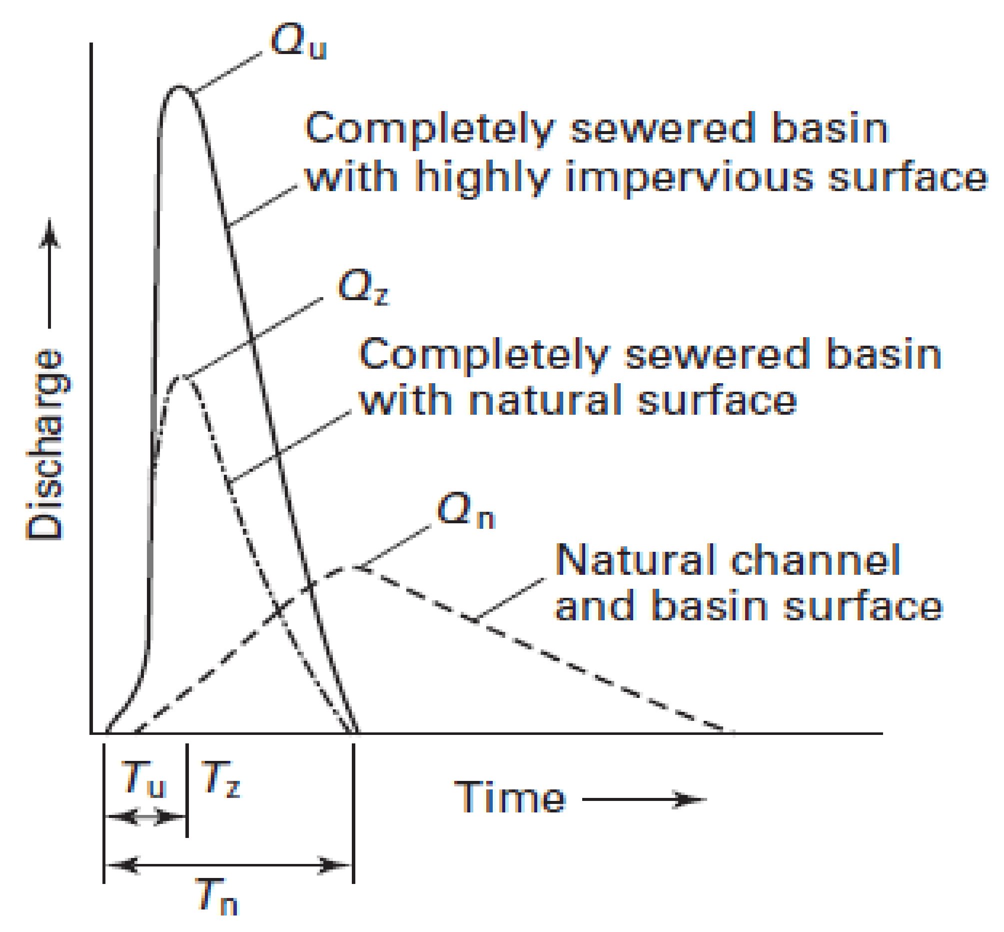
Human Impacts on nature

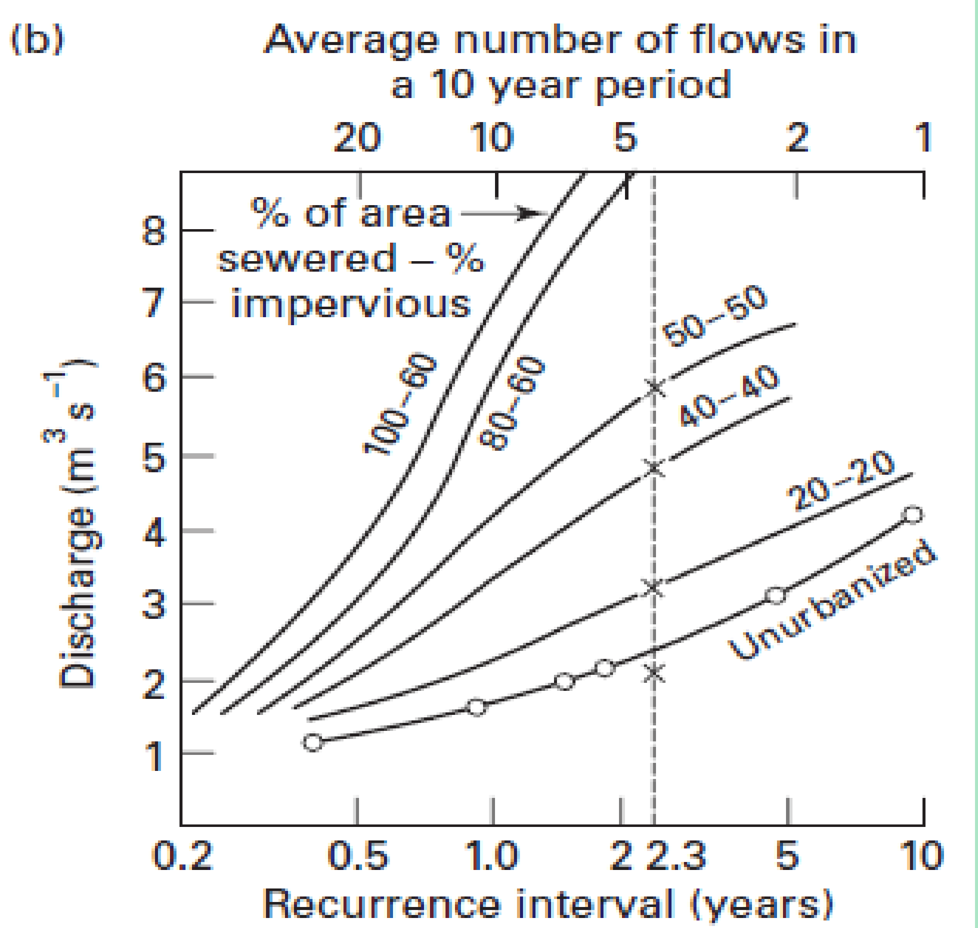


Human Impact on Nature

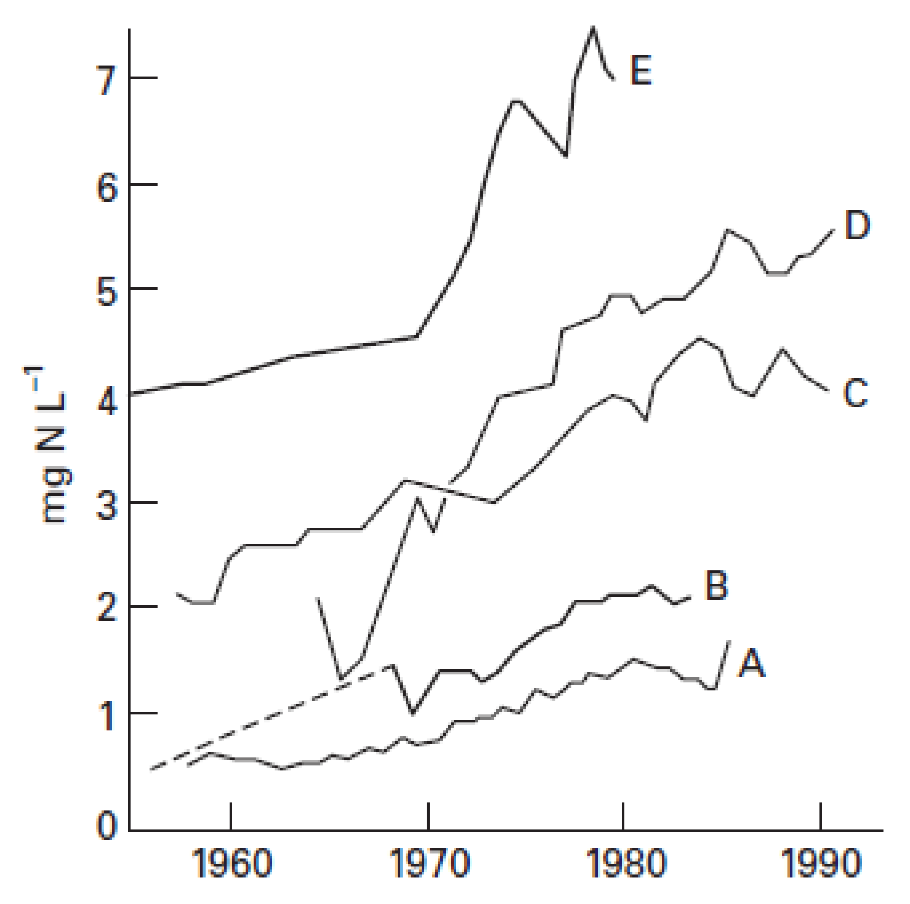


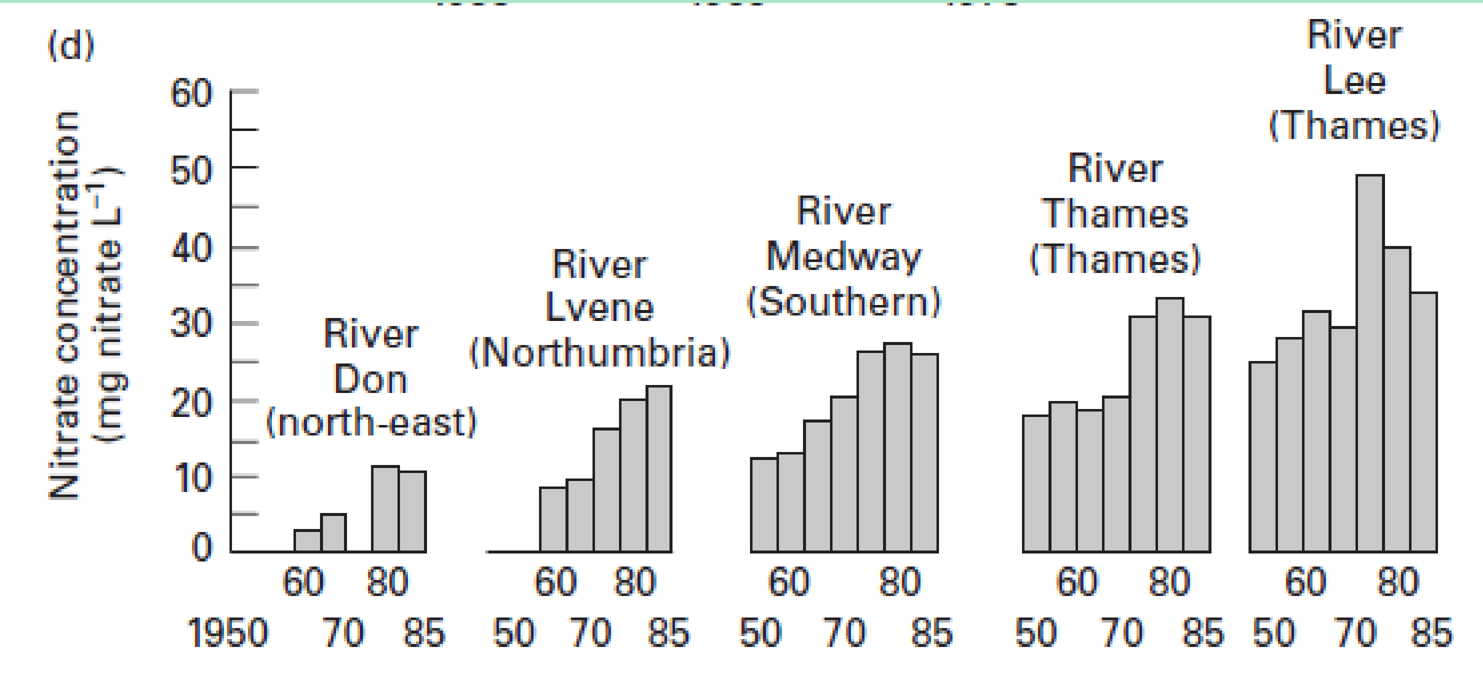
Human Impact on Nature



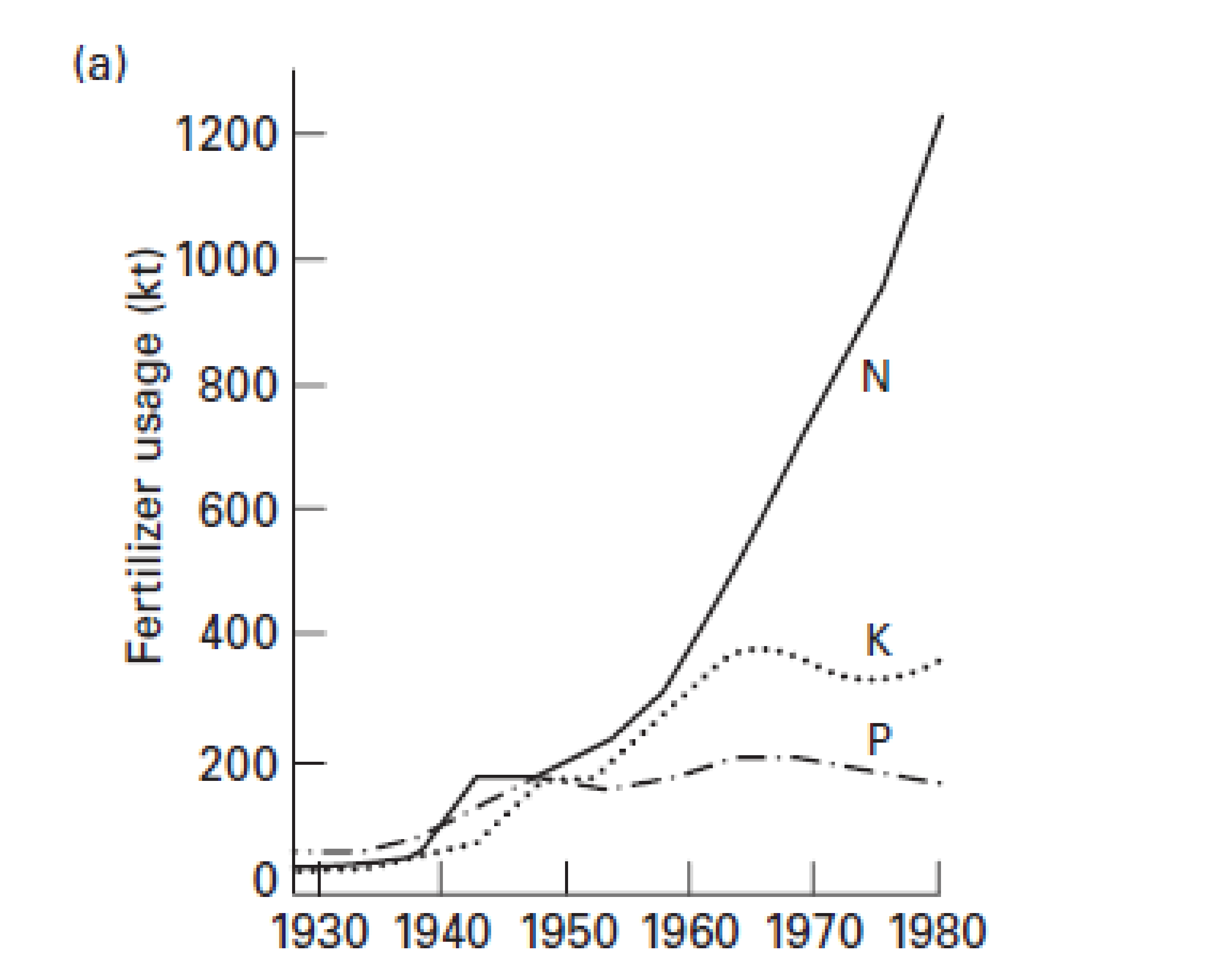


Human Impact on Nature





Human Impact on Nature



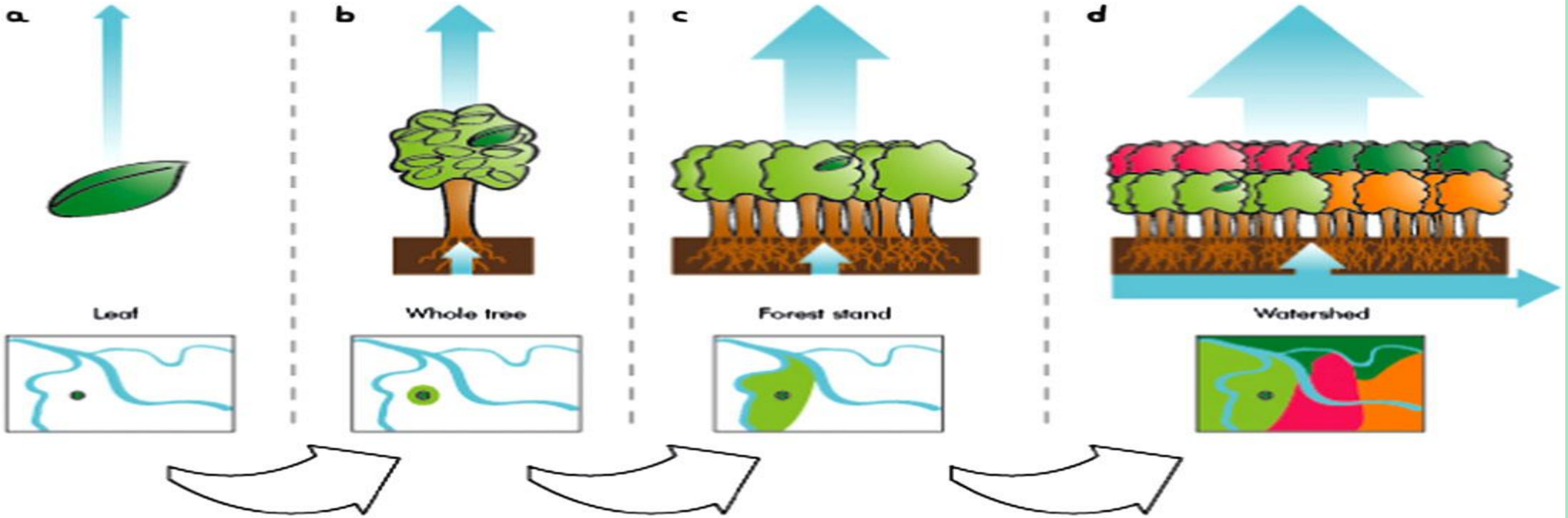
Ecohydrology Principles

Following these assumptions (Regulation, Integration, Harmonization), the concept of ecohydrology is based on three principles:

1. **FRAMEWORK** - Integration of the catchment, water and its biota into one entity, including:

a) Scale - the mesoscale cycle of water circulation within a basin is a template for the quantification of ecological processes;
b) Dynamics - water and temperature are the driving forces for both terrestrial and freshwater ecosystems;
c) Hierarchy of factors - abiotic (e.g., hydrological) processes are dominant in regulating ecosystem functioning. Biotic interactions may manifest themselves when abiotic factors are stable and predictable.

SCALING ECOHYDROLOGICAL PROCESSES FROM LEAVES TO WATERSHEDS



Ecological constraints
- leaf size
- stomatal conductance/ sensitivity
- microclimate (temp, light, VPD)
- water use efficiency
- leaf boundary layer

Hydrological constraints
- atmospheric moisture

Ecological constraints
- sapwood variation
- canopy roughness
- crown architecture
- canopy boundary layer
- rooting depth
- depth of plant water uptake
- foliar deposition of fog, dew

Hydrological constraints
- soil moisture availability
- soil physical properties (texture, porosity, depth, etc.)
- soil hydraulic conductivity
- groundwater depth

Ecological constraints
- variation in plant species and vegetative cover types
- edge dynamics (advection, fog/dew inputs)
- canopy interception
- diel coupling transpiration-streamflow

Hydrological constraints
- hydrologic flowpaths
- hydrologic connectivity
- deep drainage
- soil moisture storage capacity
- geohydrologic properties

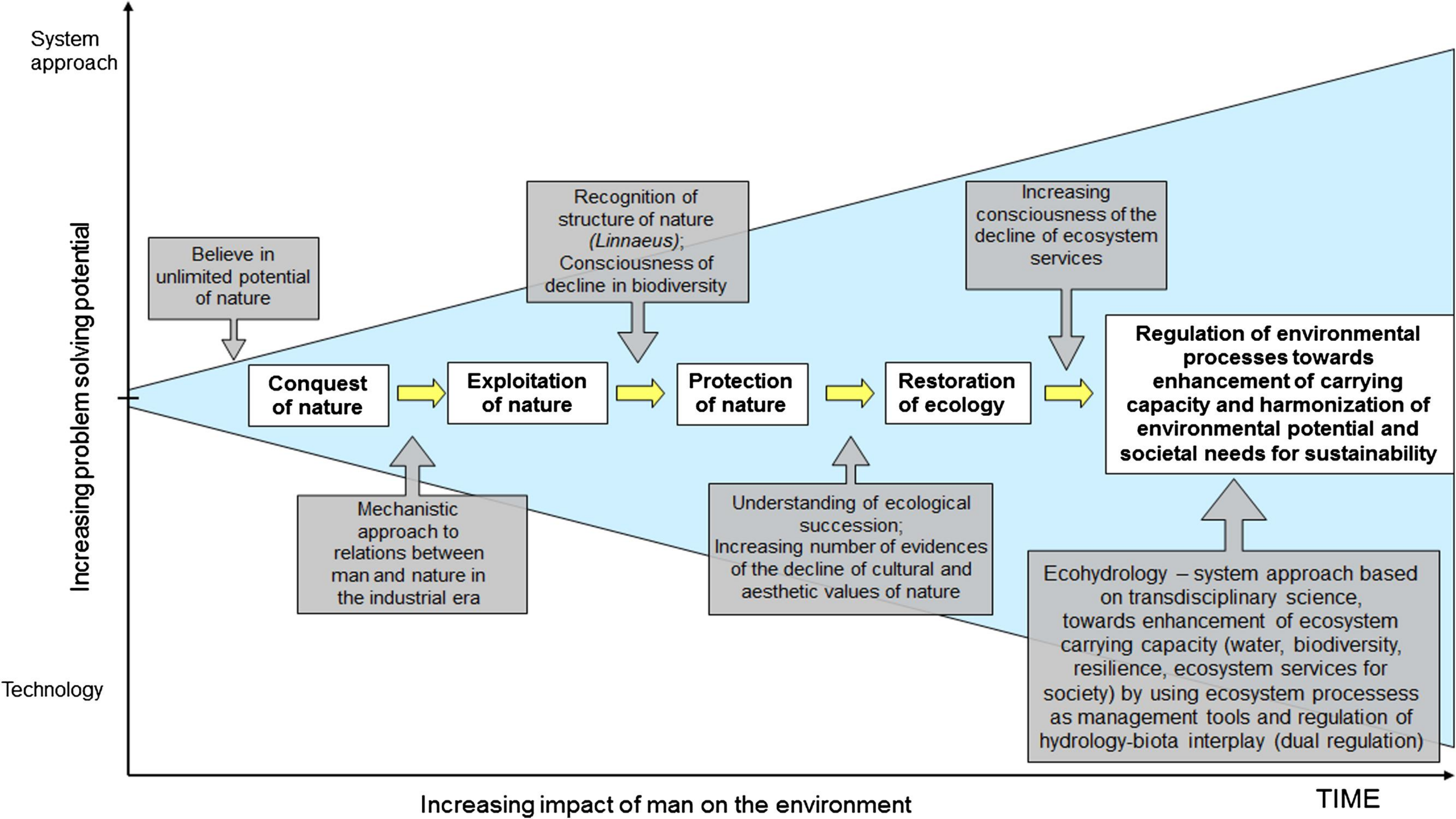
Ecohydrology Principles

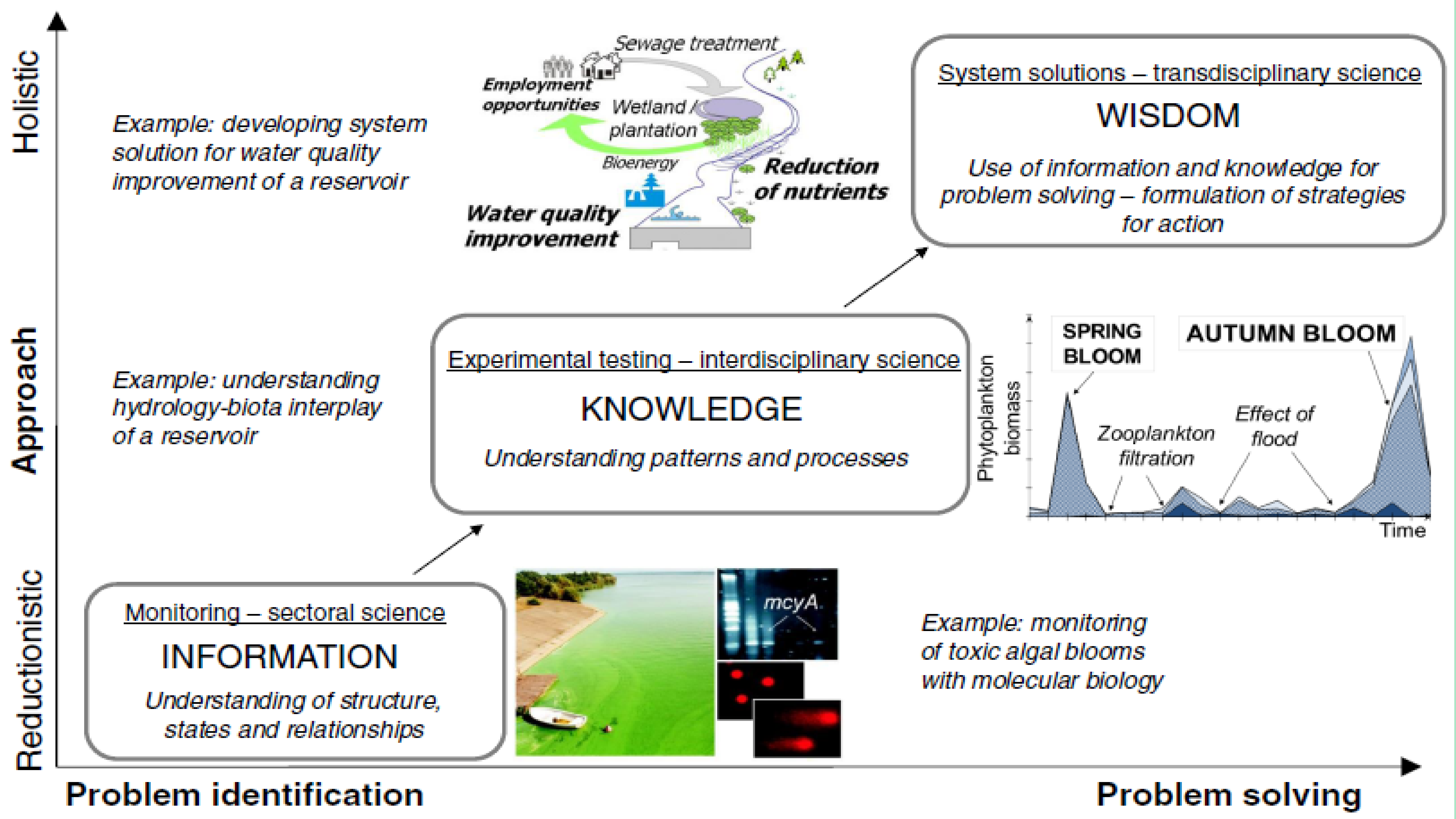
2. TARGET - Understanding evolutionarily established ecohydrological processes is crucial for a proactive approach to the sustainable management of freshwater resources.

It assumes that it is not enough to simply protect ecosystems but, in the face of increasing global changes (such as increasing population, energy consumption, global climate change), it is necessary to increase the carrying capacity of ecosystems, and their resistance and resilience, to absorb human-induced impacts.

Ecohydrology Principles

3. METHODOLOGY - ecohydrology uses ecosystem properties as a management tool. It is applied by using biota to control hydrological processes and, vice versa, by using hydrology to regulate biota. Scientific basis for the methodological aspect of using biota for water quality improvement has been seriously advanced by ecological engineering.


System approach
Technology
Increasing problem solving potential
Believe in unlimited potential of nature
Recognition of structure of nature (Linnaeus); Consciousness of decline in biodiversity
Increasing consciousness of the decline of ecosystem services
Conquest of nature
Exploitation of nature
Protection of nature
Restoration of ecology
Regulation of environmental processes towards enhancement of carrying capacity and harmonization of environmental potential and societal needs for sustainability
Mechanistic approach to relations between man and nature in the industrial era
Understanding of ecological succession; Increasing number of evidences of the decline of cultural and aesthetic values of nature
Ecohydrology – system approach based on transdisciplinary science, towards enhancement of ecosystem carrying capacity (water, biodiversity, resilience, ecosystem services for society) by using ecosystem processess as management tools and regulation of hydrology-biota interplay (dual regulation)
Increasing impact of man on the environment
TIME



Holistic
Approach
Reductionistic
Example: developing system solution for water quality improvement of a reservoir
Sewage treatment
Employment opportunities
Wetland / plantation
Bioenergy
Reduction of nutrients
Water quality improvement
System solutions – transdisciplinary science
WISDOM
Use of information and knowledge for problem solving – fomulation of strategies for action
Example: understanding hydrology-biota interplay of a reservoir
Experimental testing – interdisciplinary science
KNOWLEDGE
Understanding patterns and processes
SPRING BLOOM
AUTUMN BLOOM
Phytoplankton biomass
Zooplankton filtration
Effect of flood
Time
Monitoring – sectoral science
INFORMATION
Understanding of structure, states and relationships
mcyA
Example: monitoring of toxic algal blooms with molecular biology
Problem identification
Problem solving

Ecohydrology Applications

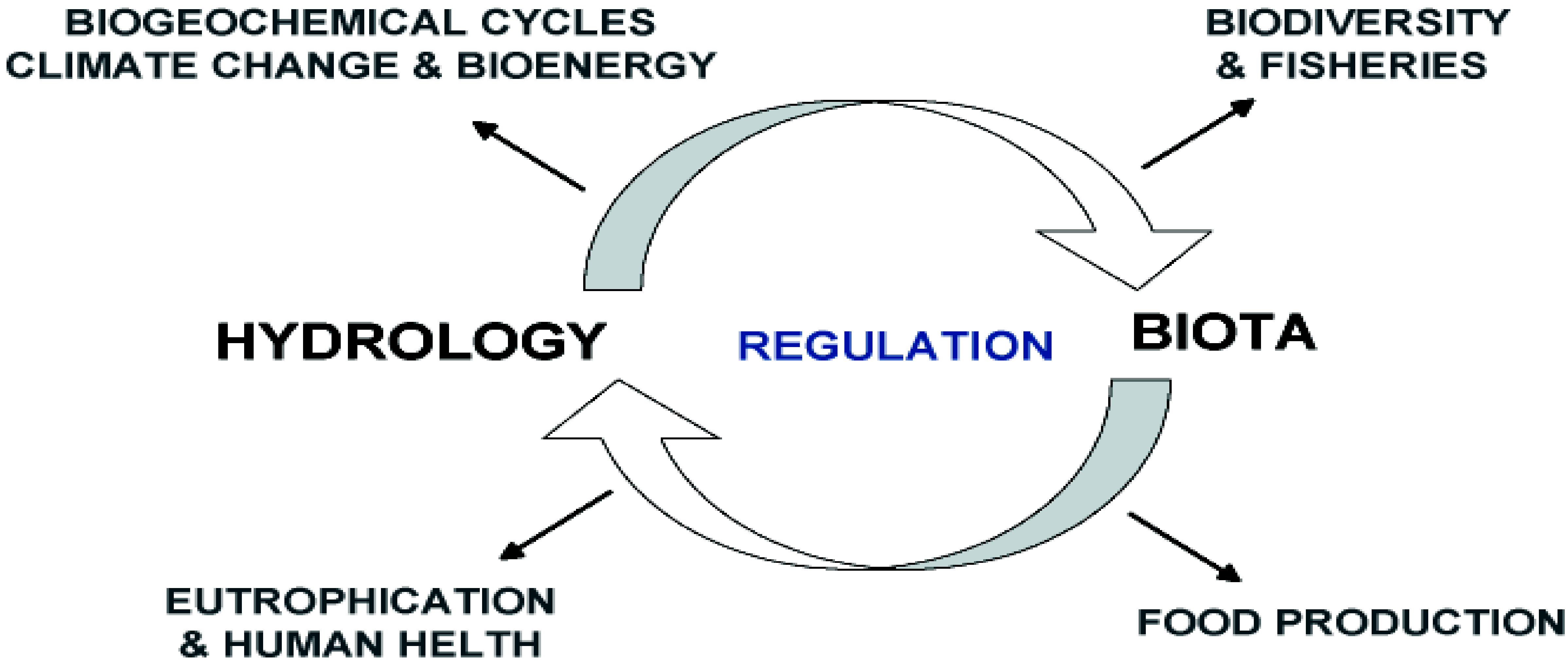
TABLE 4.4
Role of various structures in a landscape

STRUCTURE TYPE	FUNCTION IN A LANDSCAPE
built-up areas	create impermeable surfaces in the catchment and act as a pollution source, and a place for humans to expand
agricultural lands	are sources of non-point pollutants and the cause of biodiversity loss
linear anthropogenic structures	source of pollution and also participate in landscape fragmentation
meadows	are buffers of medium effectiveness against pollutants
woods and forests	efficient structures regulating rate and mode of flow of water and chemicals through a landscape
land / water transition zones	regulate the exchange ratio of water and nutrients between water and terrestrial systems
water bodies	act as both a recipient of pollutants and as a tool for reduction of nutrient content in ground water

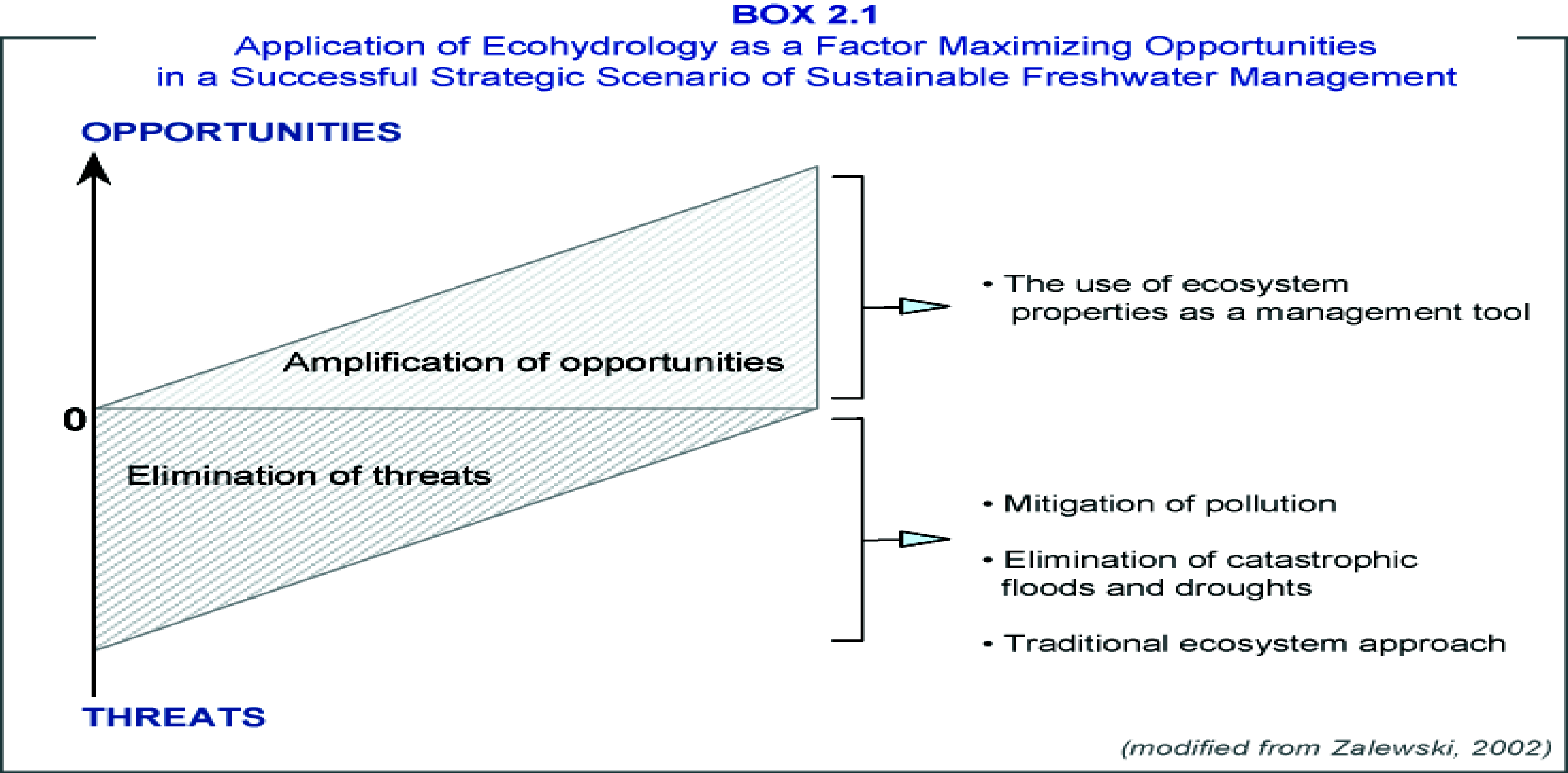
Ecohydrology Applications

Box 2.2

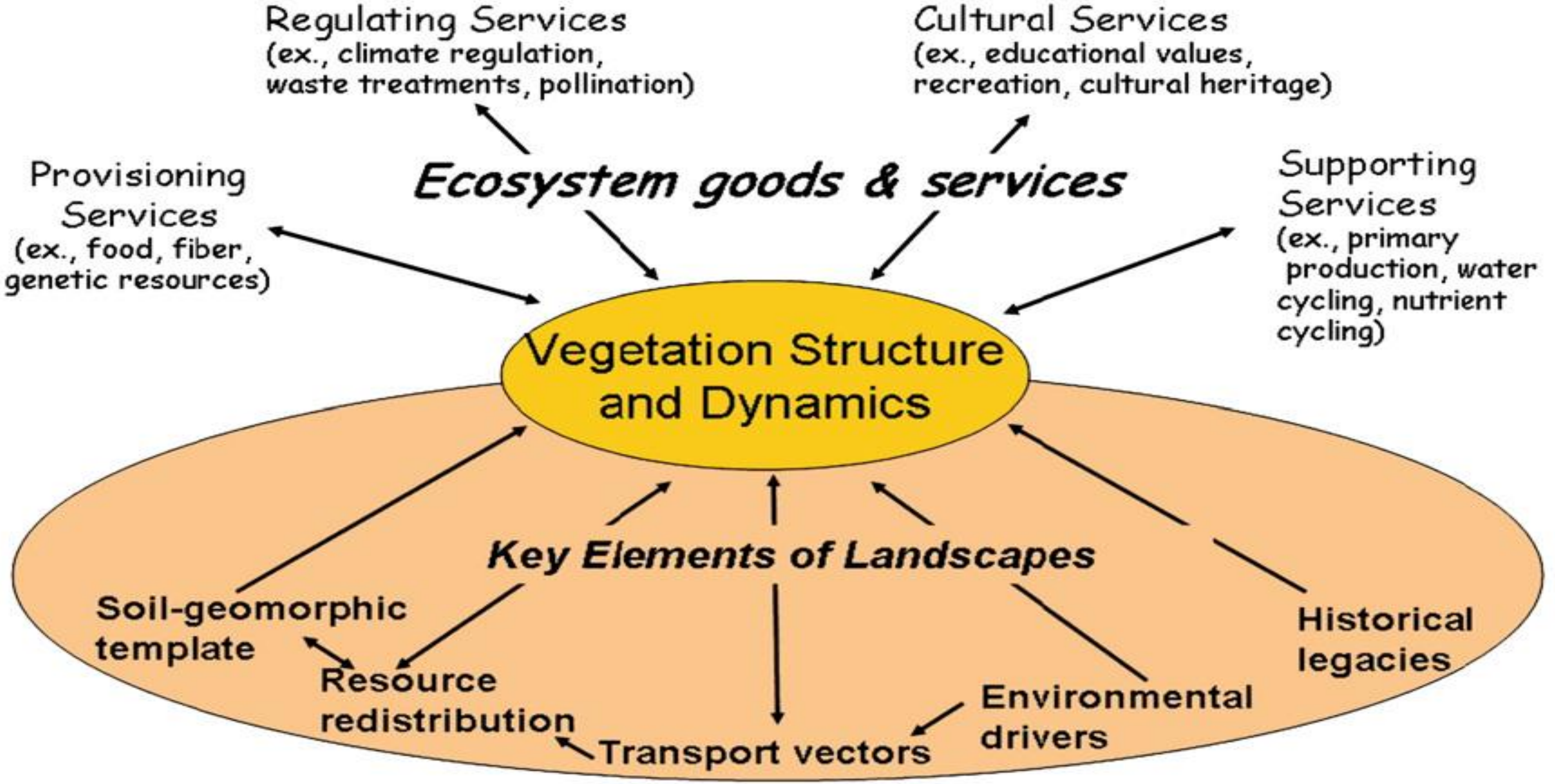
Application of Ecohydrology in problem solving



Ecohydrology Applications



Ecohydrology Applications



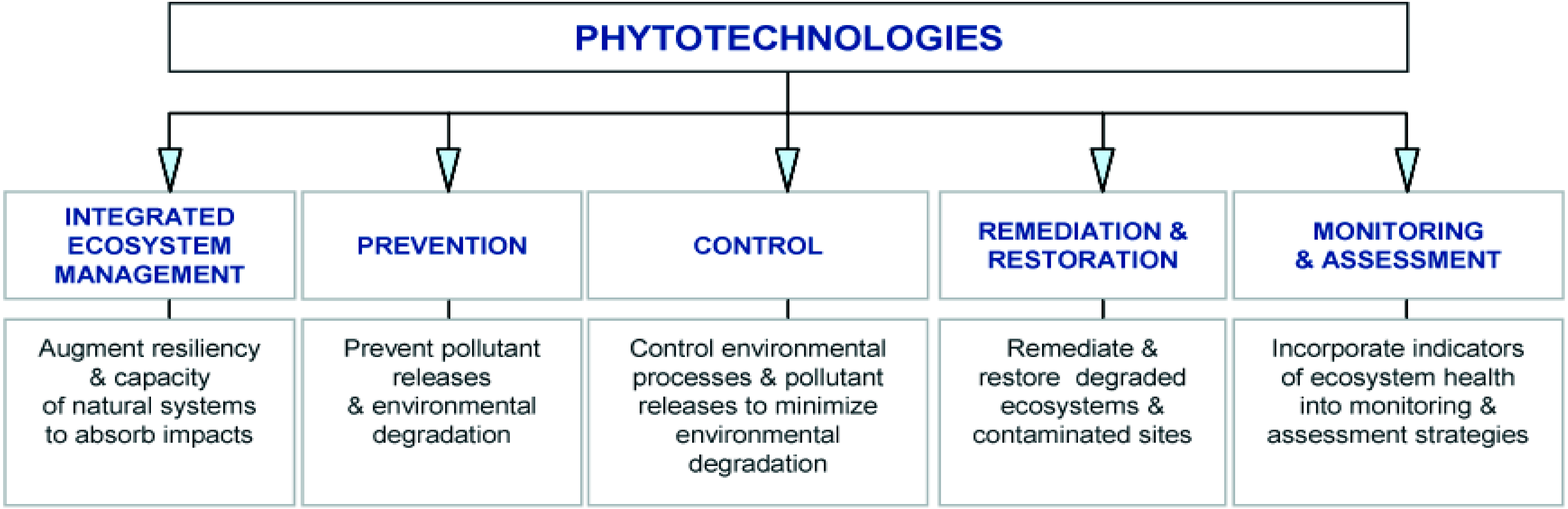
Phytotechnology

In general, the term phytotechnology describes the application of science and engineering to examine problems and provide solutions involving plants. The term itself is helpful in promoting a broader understanding of the importance of plants and their beneficial role within both societal and natural systems. A central component of this concept is the use of plants as living environmentally sound technologies (ESTs) that provide services in addressing environmental issues.

Ecohydrology Applications

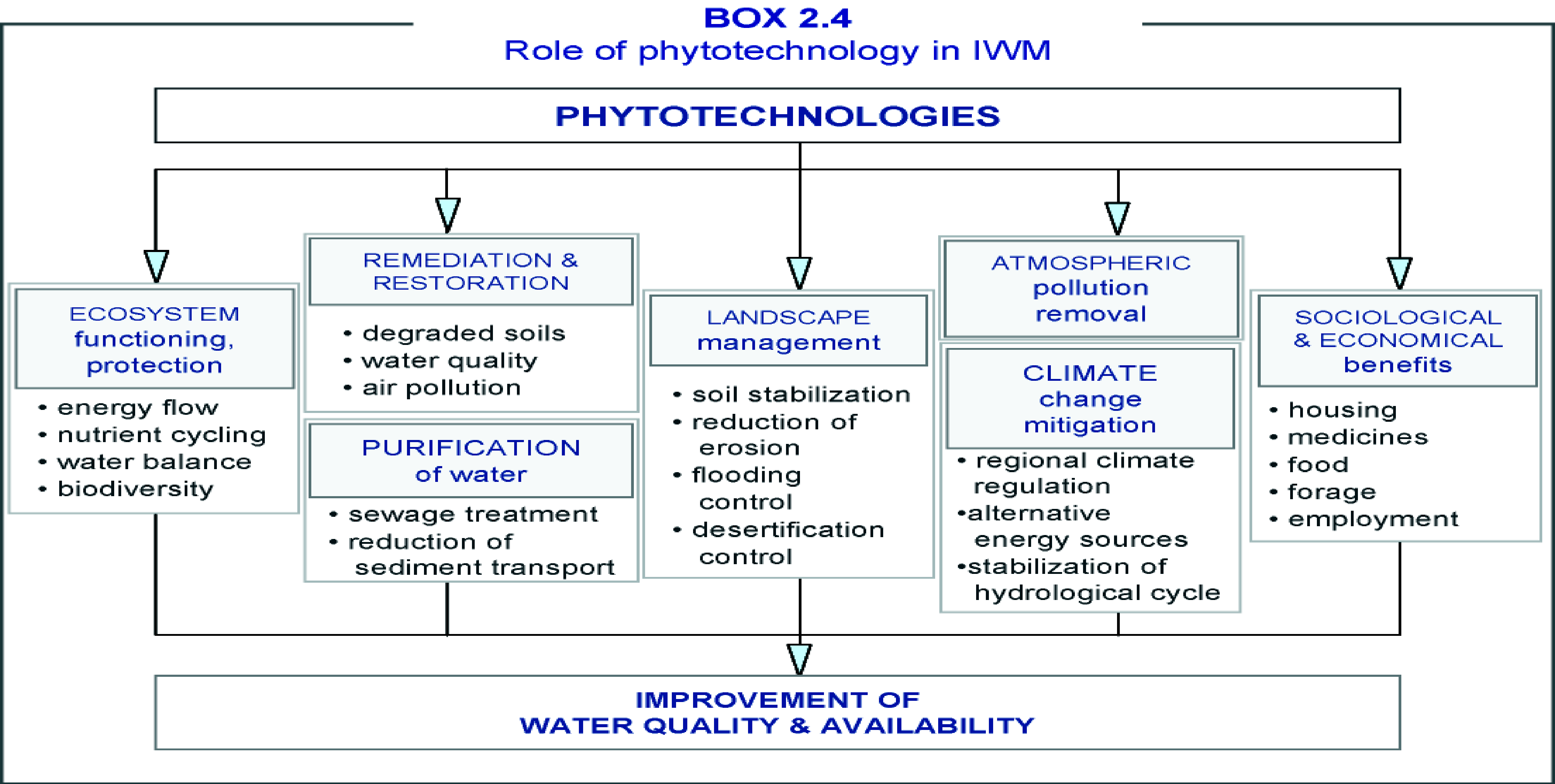
BOX 2.3

Environmentally beneficial applications of phytotechnology

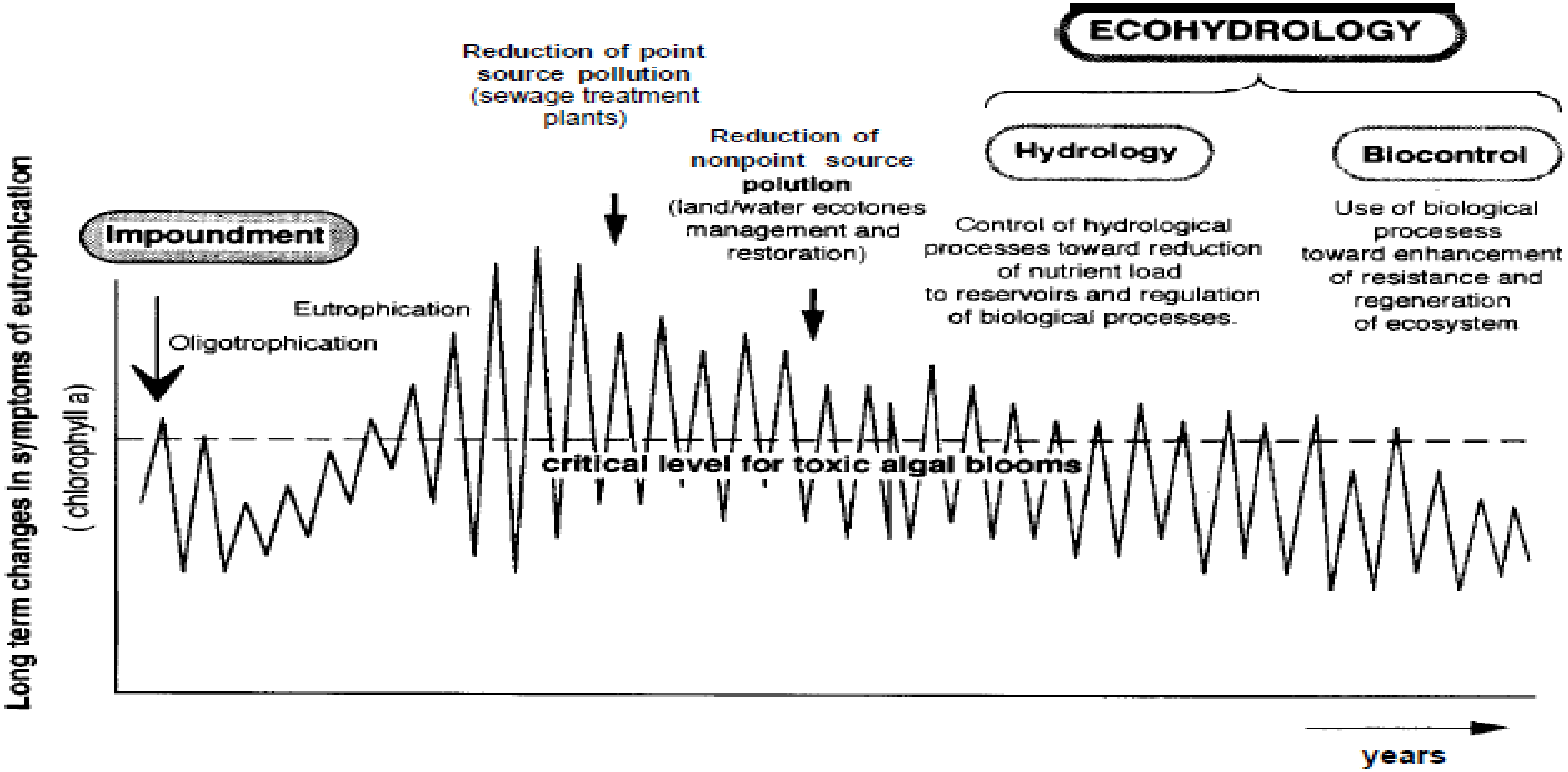


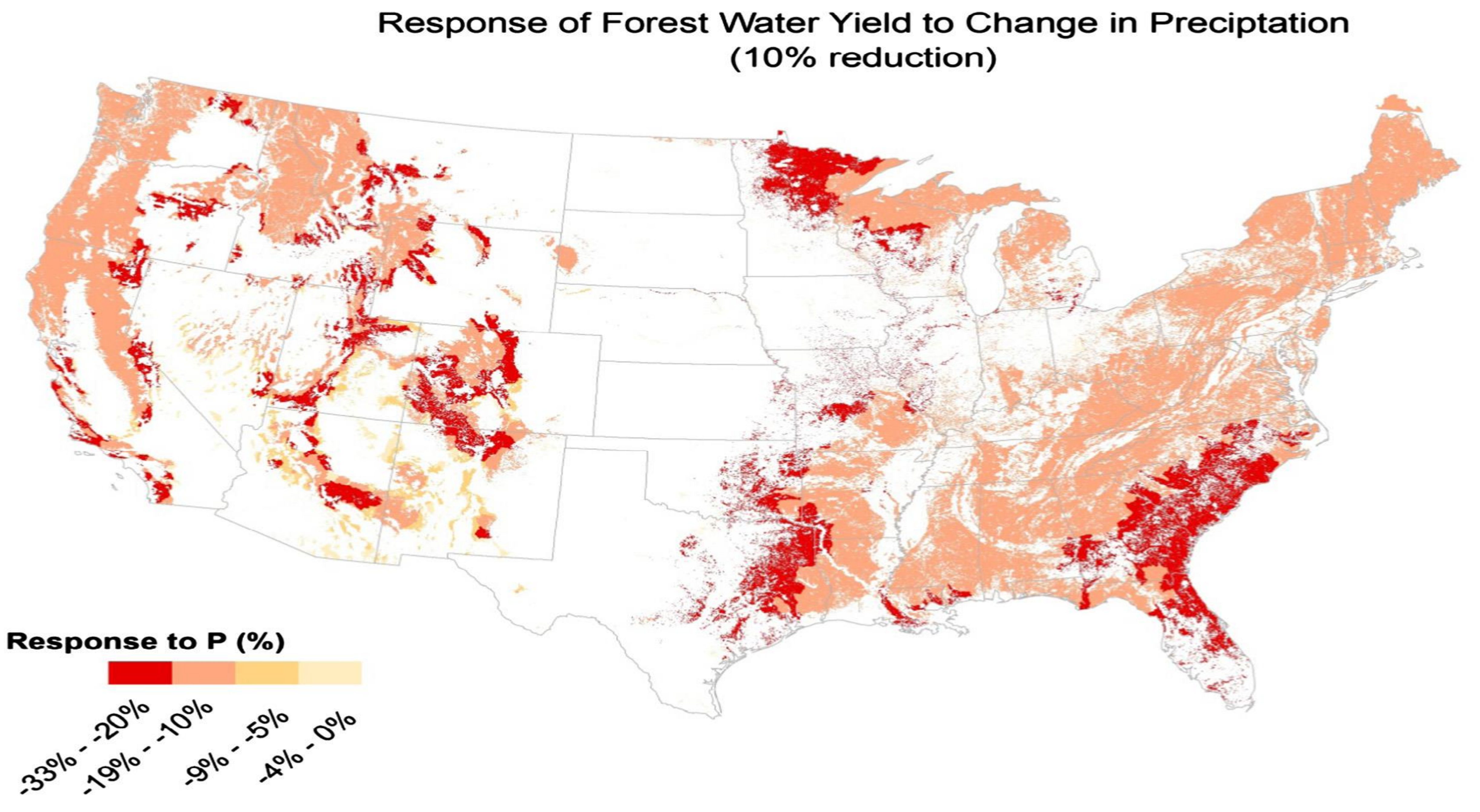
(modified from UNEP, 2003)

Ecohydrology Applications



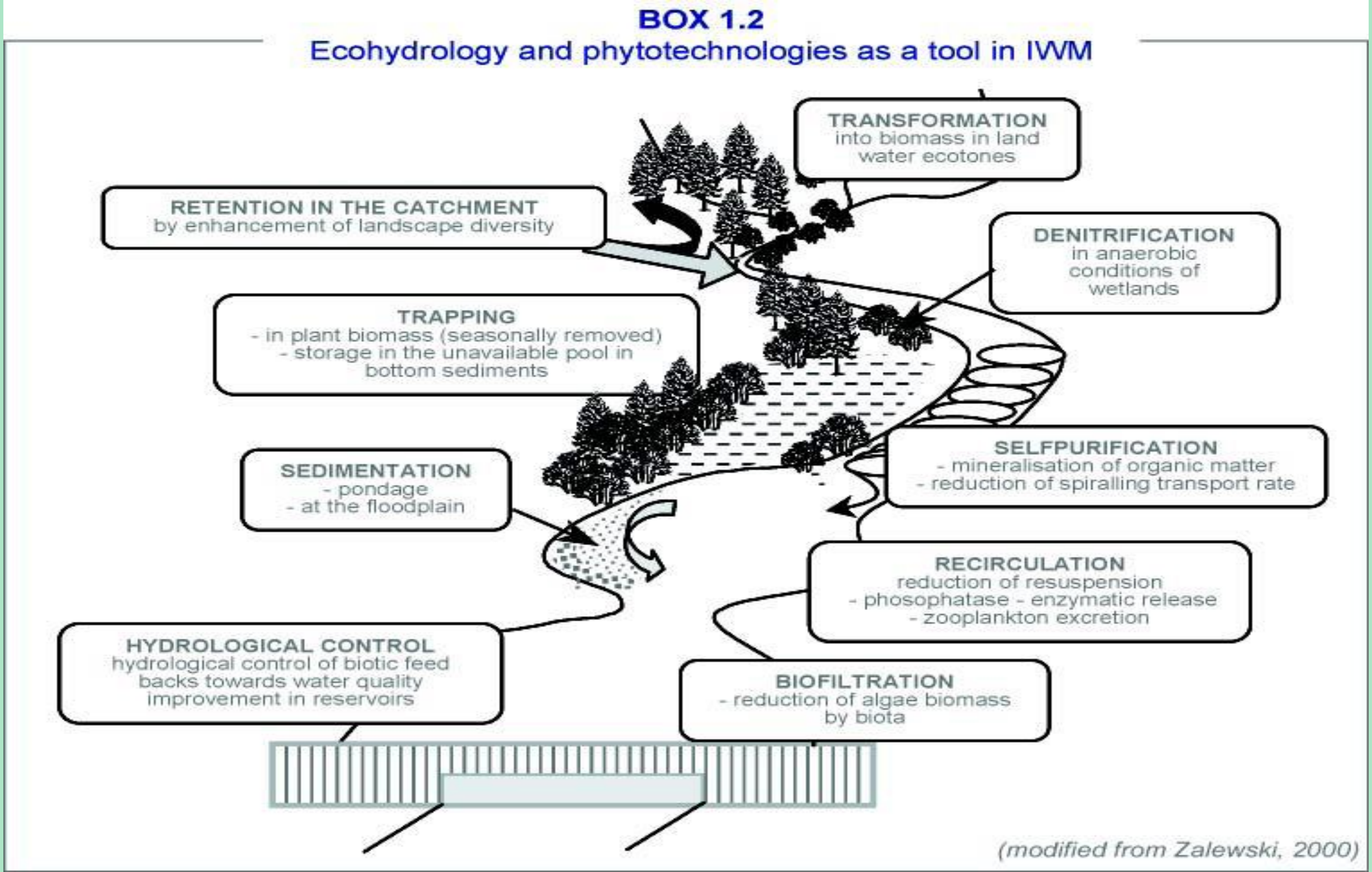
BOX 5. Hypothetical scenario of the application of ecohydrology to the restoration of eutrophic Sulejów Reservoir (Zalewski 1996).



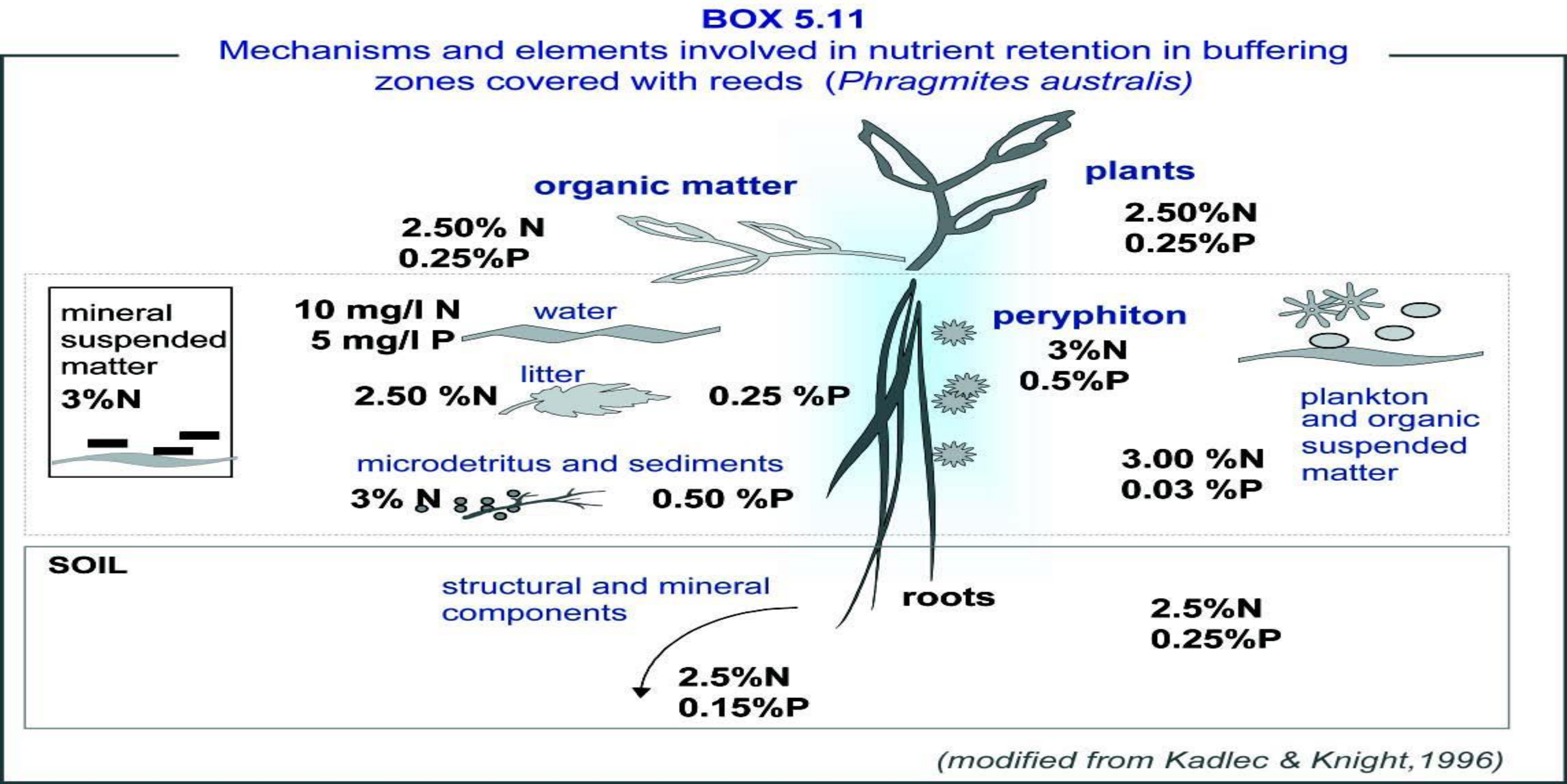


Response of Forest Water Yield to Change in Preciptation
(10% reduction)
Response to P (%)
-33% - -20%
-19% - -10%
-9% - -5%
-4% - 0%

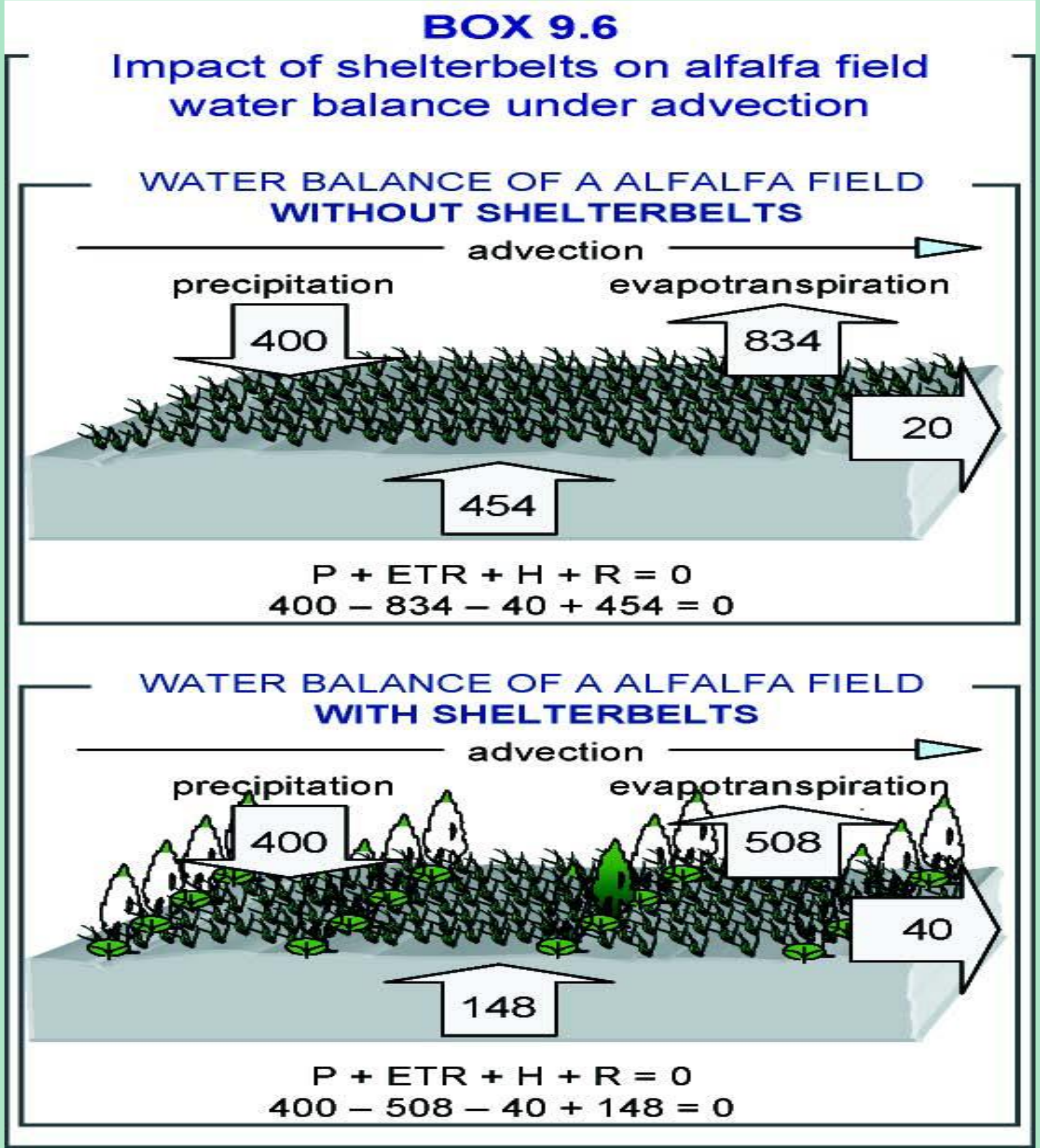
Ecohydrology Applications



Ecohydrology Applications



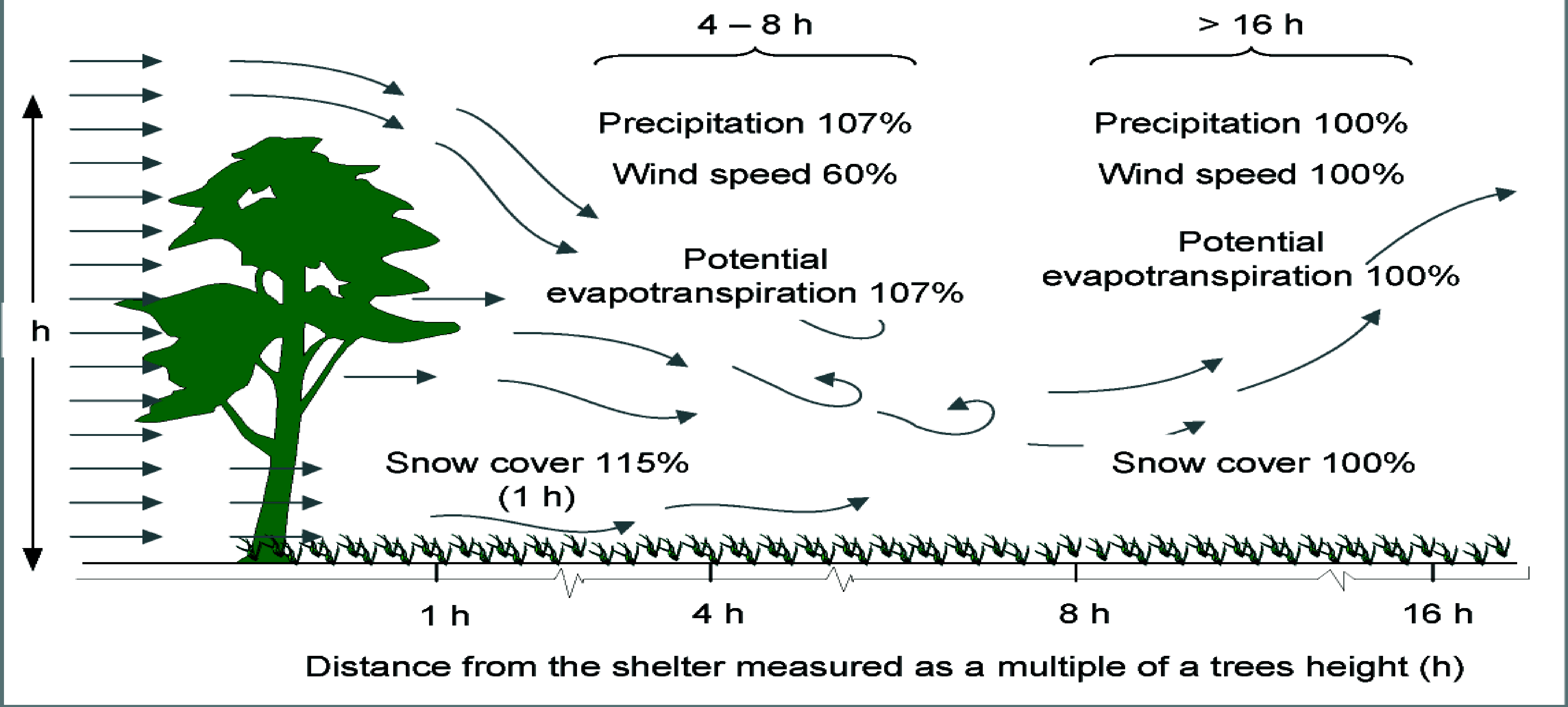
Ecohydrology Applications



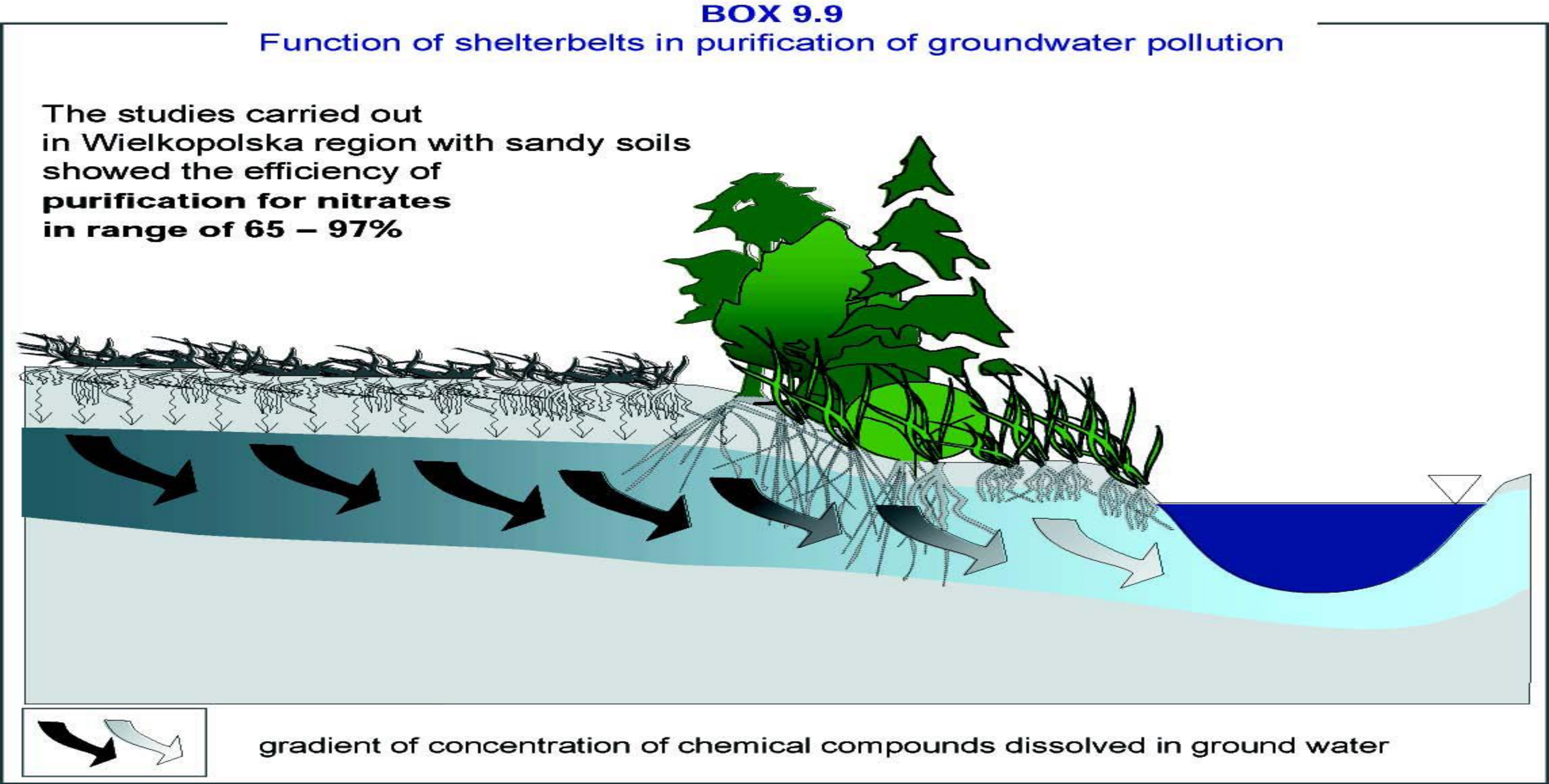
Ecohydrology Applications

BOX 9.8

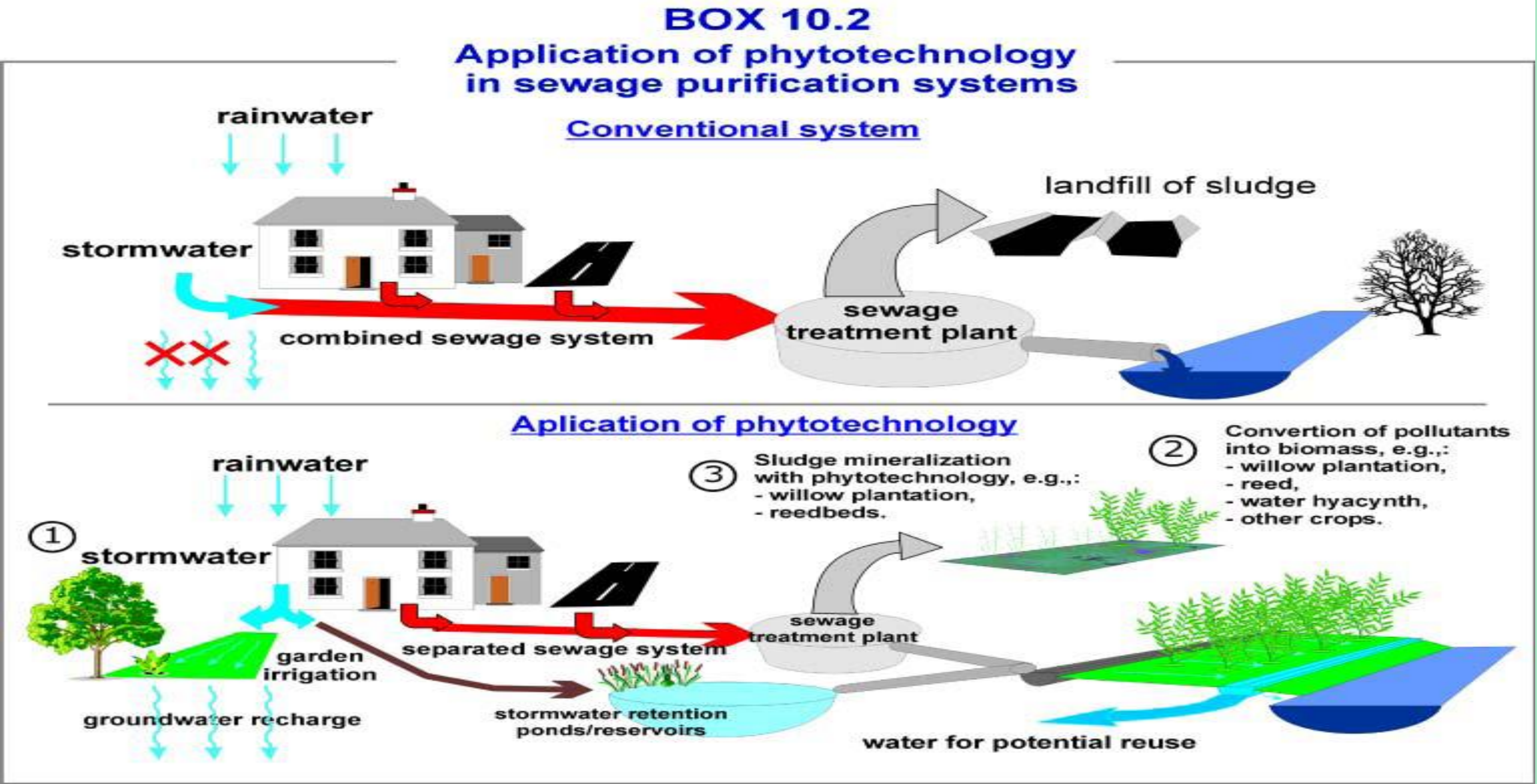
Impact of shelterbelt on microclimat of adjoining fields

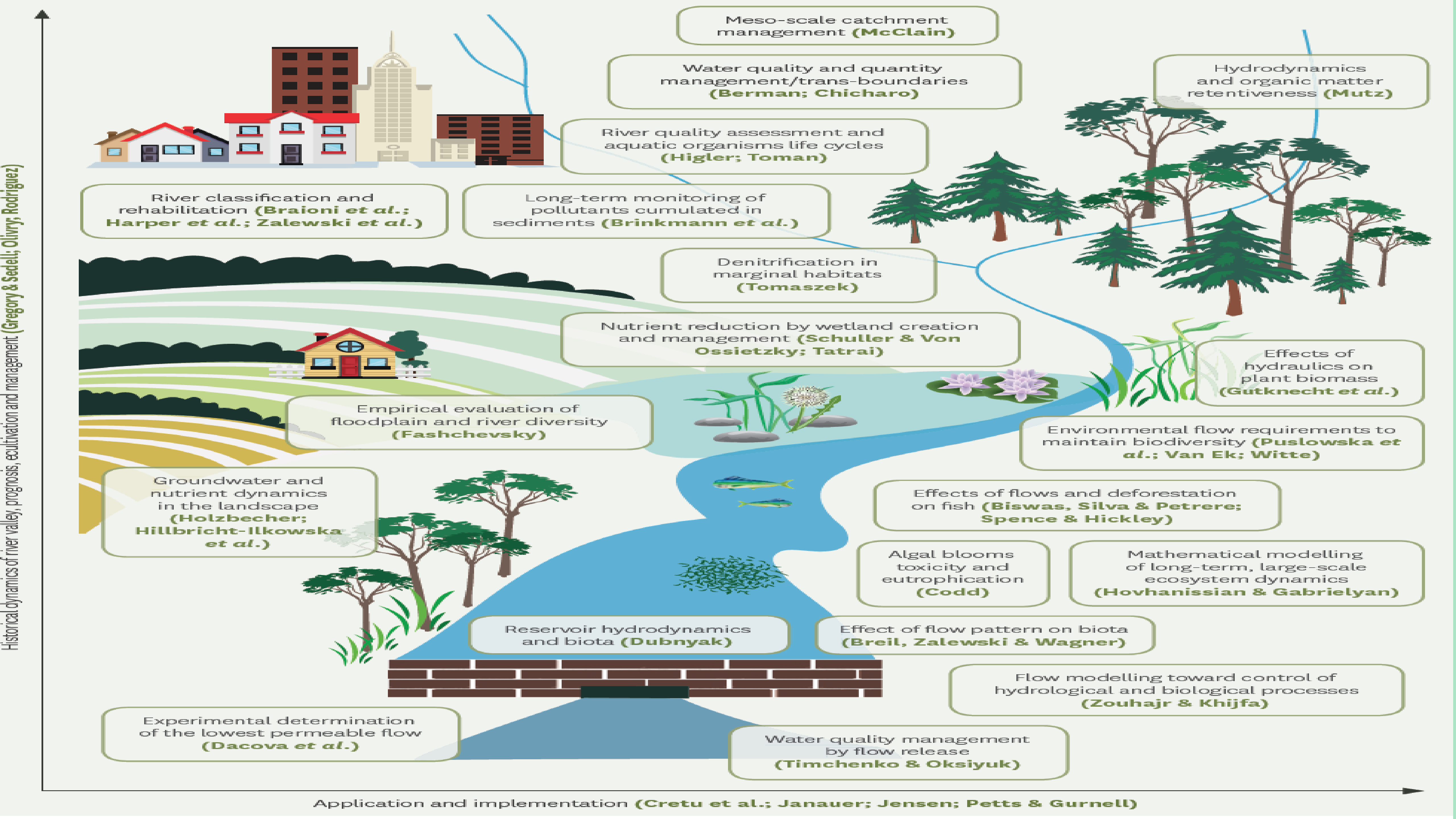


Ecohydrology Applications



Ecohydrology Applications




Meso-scale catchment management (McClain)
Water quality and quantity management/trans-boundaries (Berman; Chicharo)
Hydrodynamics and organic matter retentiveness (Mutz)
River quality assessment and aquatic organisms life cycles (Higler; Toman)
River classification and rehabilitation (Braioni et al.; Harper et al.; Zalewski et al.)
Long-term monitoring of pollutants cumulated in sediments (Brinkmann et al.)
Denitrification in marginal habitats (Tomaszek)
Nutrient reduction by wetland creation and management (Schuller & Von Ossietzky; Tatrai)
Effects of hydraulics on plant biomass (Gutknecht et al.)
Empirical evaluation of floodplain and river diversity (Fashchevsky)
Environmental flow requirements to maintain biodiversity (Puslowska et al.; Van Ek; Witte)
Groundwater and nutrient dynamics in the landscape (Holzbecher; Hillbricht-Ilkowska et al.)
Effects of flows and deforestation on fish (Biswas, Silva & Petrere; Spence & Hickley)
Algal blooms toxicity and eutrophication (Codd)
Mathematical modelling of long-term, large-scale ecosystem dynamics (Hovhanissian & Gabrielyan)
Reservoir hydrodynamics and biota (Dubnyak)
Effect of flow pattern on biota (Breil, Zalewski & Wagner)
Flow modelling toward control of hydrological and biological processes (Zouhajr & Khijfa)
Experimental determination of the lowest permeable flow (Dacova et al.)
Water quality management by flow release (Timchenko & Oksiyuk)
Historical dynamics of river valley, prognosis, ecultivation and management (Gregory & Sedell; Olivry; Rodriguez)
Application and implementation (Cretu et al.; Janauer; Jensen; Petts & Gurnell)

Ecohydrology Applications

PAST

1. Hydrology focused on control of catastrophic events and water supply
2. Descriptive ecology
3. Restrictive conservation aquatic ecosystem

↓

Generation of sustainability concept

PRESENT

ECOHYDROLOGY

Integration of Ecology + Hydrology
Improvement of predictive abilities of large scale, long term processes as a background of sustainable management

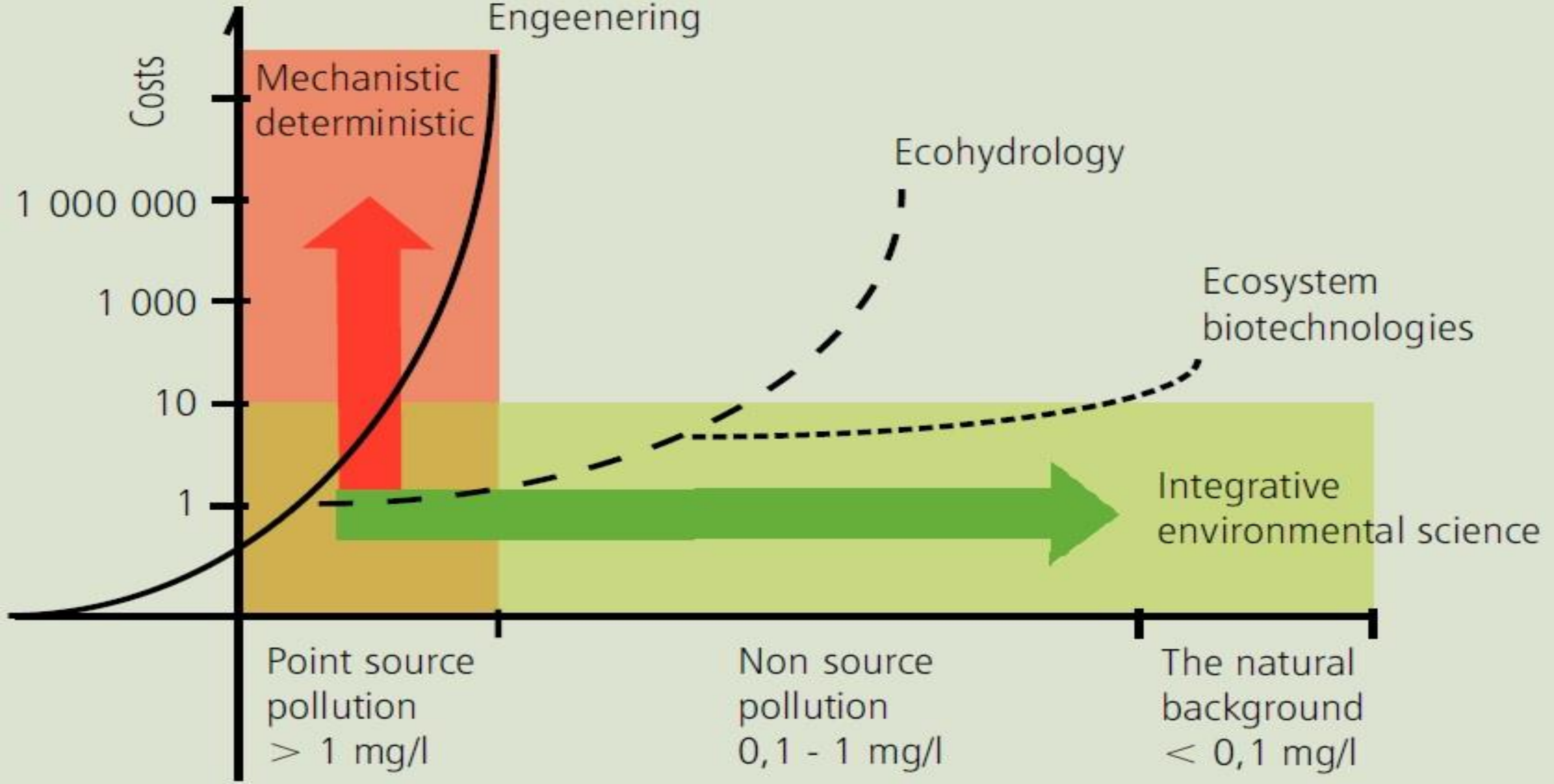
FUTURE

1. Ecohydrology as a tool for sustainable use of aquatic resources
2. Analytical/functional ecology
3. Integrated and creative conservation of freshwater resources

↓

Operational stage of sustainable management of freshwater resources

Ecohydrology Applications



Ecohydrology Applications

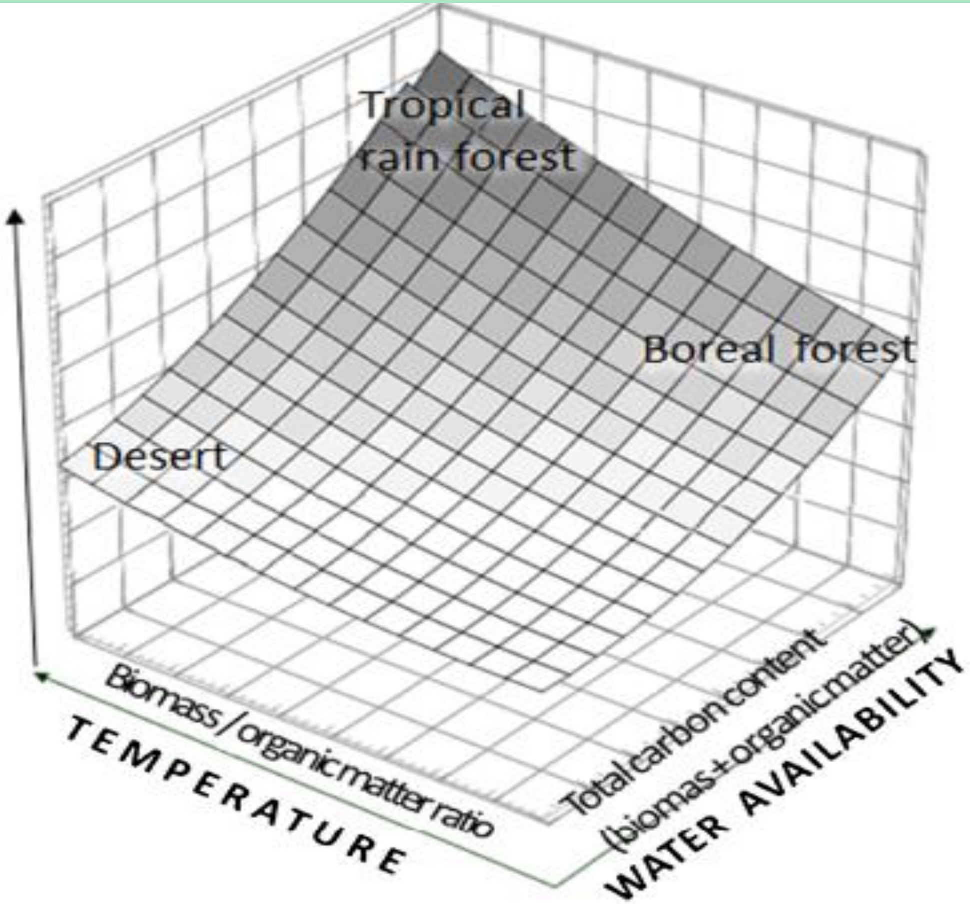
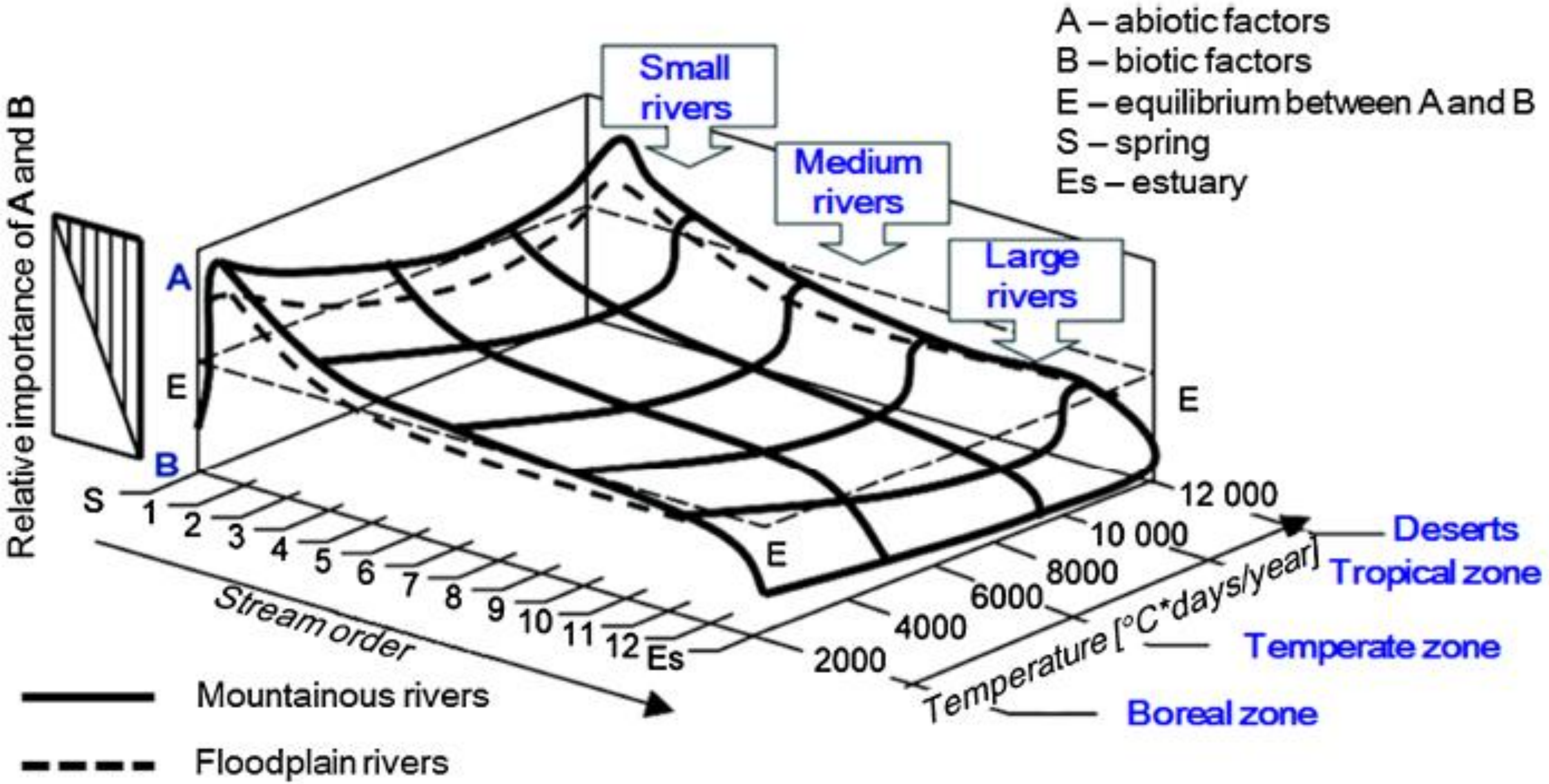
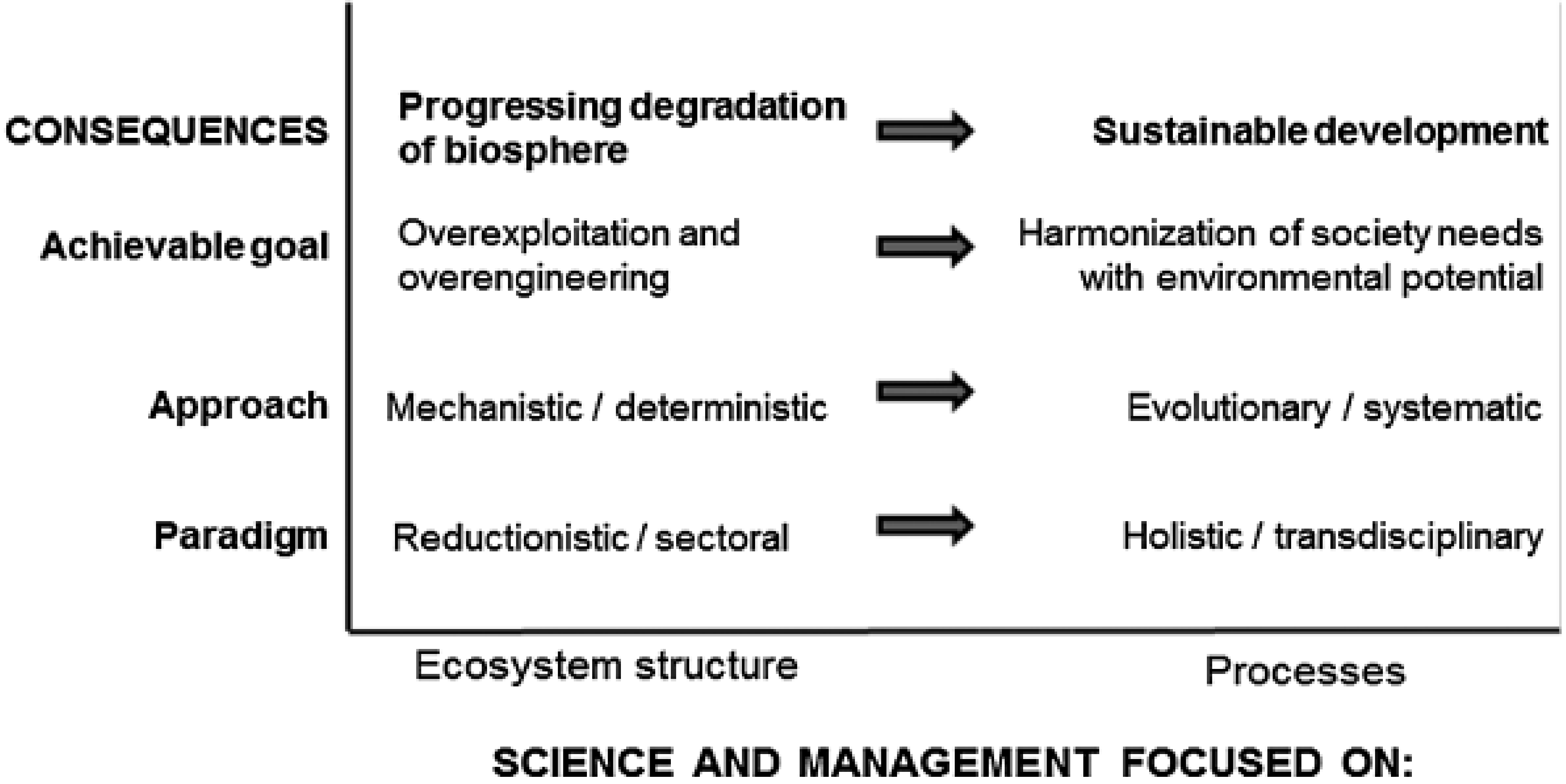


Fig. 2. Deductive background of ecohydrology theory, terrestrial phase, drivers of biodiversity; the amount of water determines the amount of carbon accumulated in an ecosystem while temperature determines the carbon allocation between biomass and soil organic matter; the maximum biodiversity and bioproductivity is achieved at highest water availability and highest temperatures (Zalewski 2002a, with permission from Taylor and Francis Ltd., http://www.tandfonline.com)

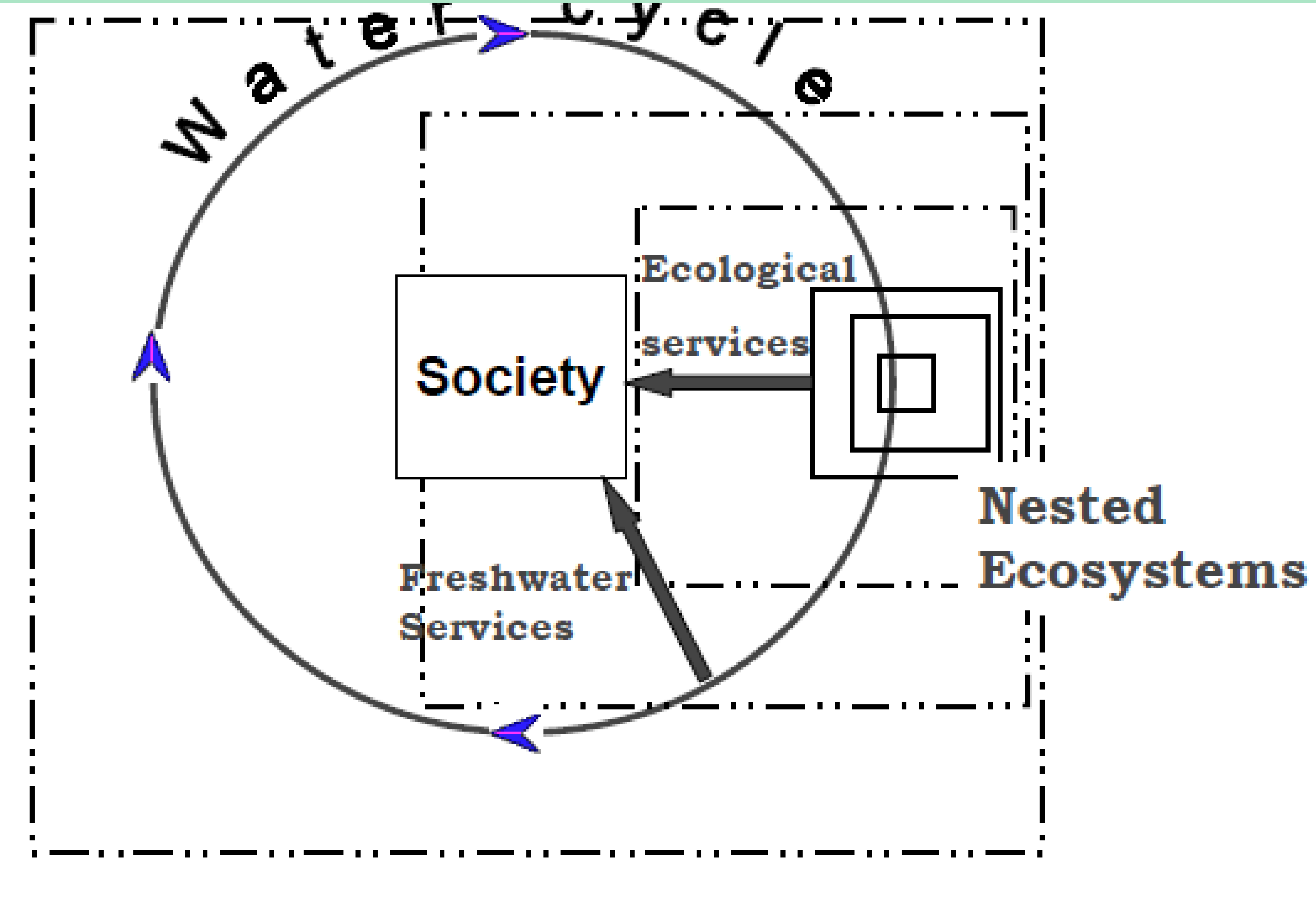
Ecohydrology Applications



Ecohydrology Applications



Social Ecohydrology



Social Ecohydrology

THE HUMAN-ENVIRONMENTAL RELATIONSHIP

Human social and cultural beliefs and practices	<<==>>	Material environment Ecosystems Hydrological systems

Social Ecohydrology

SOCIAL AND CULTURAL SYSTEMS

- Religious and secular beliefs and values.
- Social and spatial organisation.
- Economic organisation and forms of production.
- Political organisation, governance.
- Legal and moral systems.

Social Ecohydrology

MEANINGS ENCODED IN WATER

- Religious and secular meanings: water as a (re)generative substance of life and health for humans, animals and plants, and whole ecosystems.
- Social meanings: water as a collectively shared social 'substance', integral to identity and vulnerable to pollution.
- Economic meanings: water as a symbol of wealth and productivity.
- Political meanings: water as a source of power.
- Moral meanings: water as a human right, a common good.

Social Ecohydrology

PRINCIPLES OF SOCIAL ECOHYDROLOGY

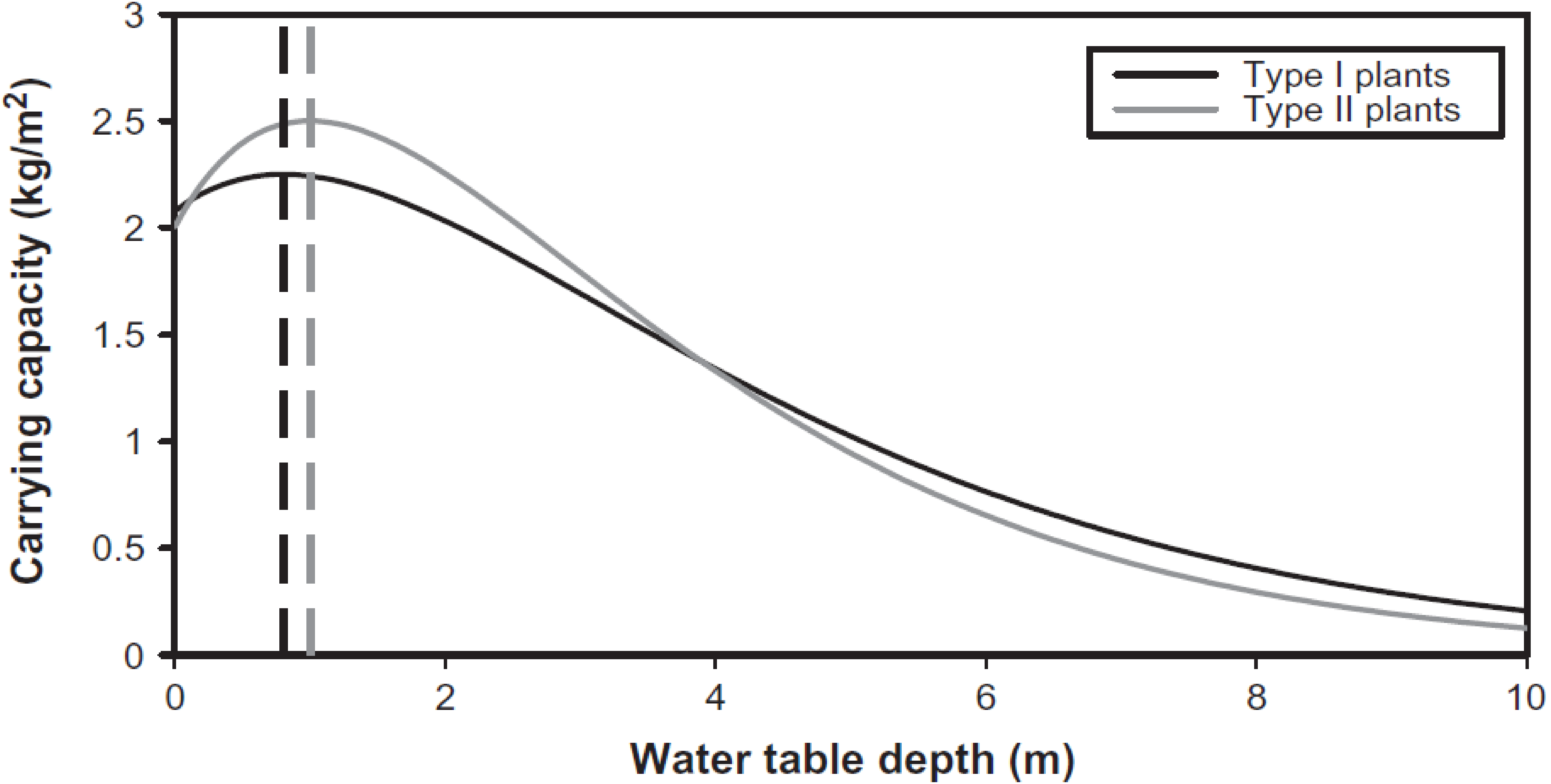
- It encompasses social, ecological and hydrological data.
- It recognises that social and natural science data represent two 'halves' of a whole human-environmental interaction, and treats them with equal weight.
- It allows for the inclusion of both qualitative and quantitative data.
- It organises data systematically.
- It is navigable, enabling analytic movement around the 'landscape' of data, and comparison between datasets.

Social Ecohydrology

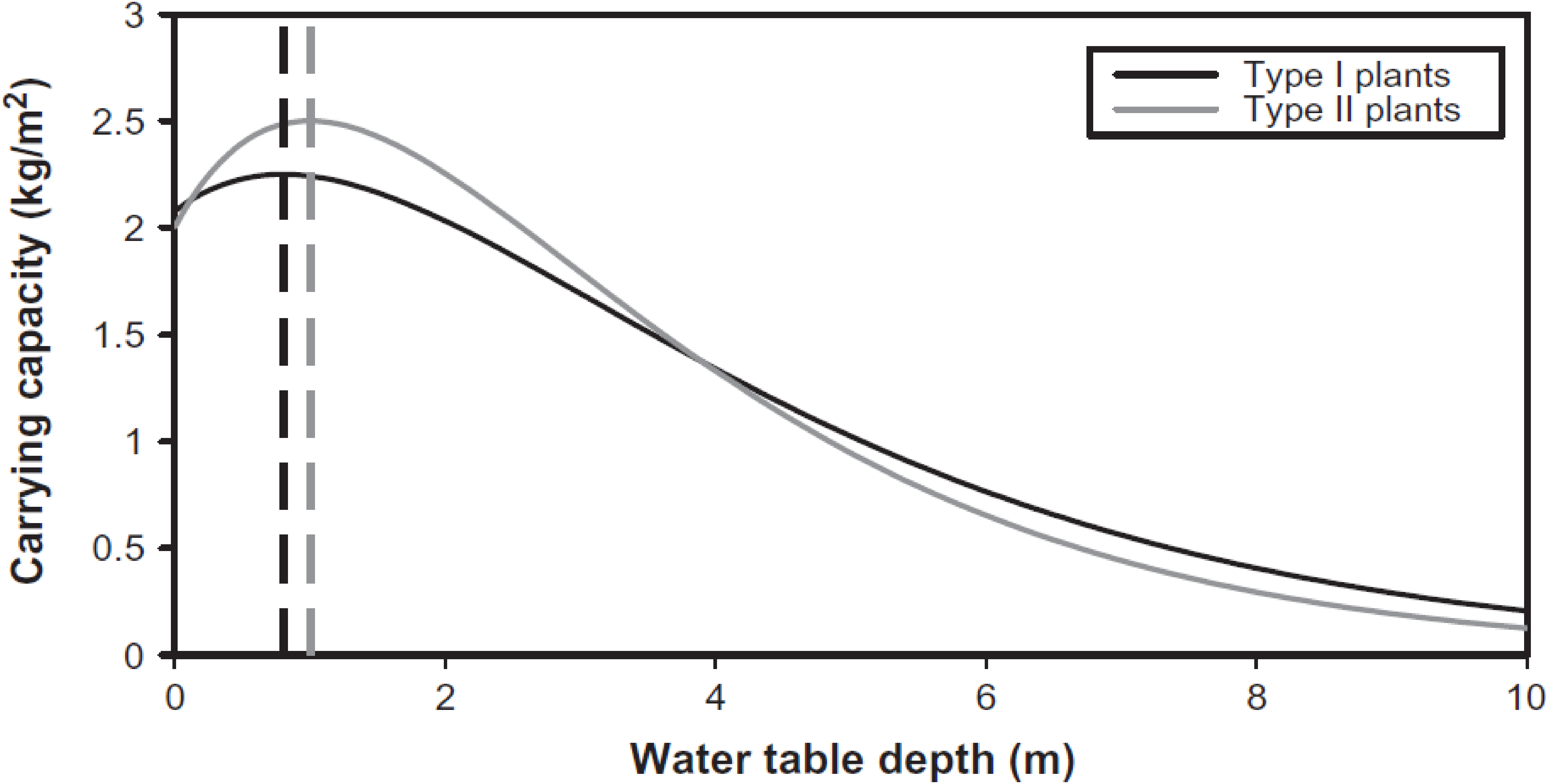
SOCIAL AND CULTURAL SYSTEMS

- Religious and secular beliefs and values.
- Social and spatial organisation.
- Economic organisation and forms of production.
- Political organisation, governance.
- Legal and moral systems.

Groundwater and Plants



Groundwater and Plants



Watershed Setting

1. **physical template:** This section covers the physical processes which are shaping forces of ecosystems. Climate, hydrology, and geomorphology provide the template upon which all life is ultimately based.
2. **The biological setting:** This section discusses the terms and concepts associated with ecosystem science as it relates to living plant and animal communities.
3. **Natural systems concept:** This section discusses how watersheds behave as natural systems and describes how different-sized watersheds operate on various spatial and temporal scales.

Watershed Functions

Category	Examples
Ecological Functions	• Provision of sufficient water with a minimum required quality, • Provision of minimum water flow over time, • Provision of other goods and services from natural resources e.g. erosion control, soil fertility biodiversity, clean air, carbon sequestration.
Economic Functions	• Provision of sufficient natural resource products (food, fuel wood, timber, water, fish, (hydraulic) energy required for basic needs of the local population, • Provision of income generating opportunities. • Sustain livelihoods
Social and Cultural Functions	• Maintenance of social structures, • Protection and development of knowledge and lifestyle arrangements, • Maintenance and revitalization of cultural identity and values, • Recreational facilities

Watershed Functions

1. **The Collection Function:** How runoff is collected within the watershed depends upon storm position and size relative to basin size, storm proximity to runoff source areas within the watershed, and precipitation type and intensity. Ultimately, these are critical issues of relative scales of the watershed and the runoff-producing event. Two of these issues are particularly relevant. The first is whether the event completely covers the watershed, and the second is where on the watershed the storm is located if it is smaller than the watershed.

2. **The Storage Function:** The type, amount, and distribution of storage are thee primary watershed characteristics that affect the storage function. As the function that is intermediate between the collection and discharge functions, some storage characteristics play an intervening, complex, and interacting role among all three functions.

Watershed Functions

3. The Discharge Function: The ultimate fate of runoff waters within a watershed is to be output from the basin, as depicted in the hydrograph, the record of the discharge function. Discharge takes place as the functions of collection and storage are played out over time scales varying from that of a runoff-causing event to a hydrologic year. Clearly, factors that affect the collection and storage functions also affect the discharge function, and are represented in both the storm and annual hydrographs.

4. The Chemical Function: Water is the principal medium in which most chemical reactions occur; watersheds provide diverse aqueous sites in which those chemical reactions take place. Over time, these reactions have ranged from those preceding beginnings of life on Earth to those affecting the movement of pollutants and unwanted nutrients in the modern aquatic environment.

5. The Habitat Function: Life on Earth takes place in the presence of water. The fluids of living organisms are like that of the oceans. One popular theory is that the "higher" living organisms on Earth developed in an aqueous environment. The evolution of humans most likely occurred at diverse and protective seashore environments (as opposed to the rather hostile savannah). Wherever the human species evolved into its current form, other mammals thrived and made similar dramatic changes in appearance and behavior.

Watershed Functions

Location of Benefits	Economic Benefit	Watershed Service[6]	Economic Valuation Study
Upstream	**Reduced crop losses**	**Soil quality maintenance**: Reduced soil erosion, and loss of soil depth and fertility	**Morocco**: Loukkos Watershed. Brooks et al (1982)
	Value of e.g. forest products	**Land/Water Productivity**: conservation strategies: e.g. afforestation, provide livelihoods	
	Improved livestock and produce	**Land/Water Productivity**: conservation strategies: e.g. pasture management, provide livelihoods	**Nepal**: Phewa Tal Watershed. Fleming, Hufschmidt et al (1986)
	Increased crop yields	**Soil quality maintenance**: ecological benefits: increased soil organic matter, moisture retention etc.	**Mali**: Bishop & Allen (1989)
Downstream	**Improved Water Availability**	**Water Yield**: inter-sectoral reallocation of surface water yield from surface water management or optimal control of groundwater coupled to surface water	**USA, Colorado**: Howe (2000)
	Irrigation Benefits	**Water quality maintenance**: Improved yields through water quality improvement and reservoir yield	**Java**: Repetto et al (1989)
	Hydropower generation	**Water quality/sediment retention and water yield**: Reduced siltation of storage dams, increased inflow	**El Salvador**: Acelhuete Catchment. Wiggins and Palma, (1980)
	Flood damage prevention	**Water flow smoothing**: Reduced runoff in high rainfall periods	**USA**: North Carolina. Freund & Tolley (1966)
	Drought Mitigation	**Water storage**: increased groundwater for drought years	**Indonesia**: Manggarai watersheds. Pattanayak & Kramer (2001)
	Fisheries Benefits	**Water quality**: Increased yields from improved water quality	**Australia**: New South Wales. Sinden (1990).
	Domestic and other Industrial	**Water yield and quality**: Improved water quality, reduced treatment costs, reduced siltation of storage dams, increased yield	**Morocco**: Loukkos Watershed. Brooks et al (1982)
	Amenity	**Environmental/ecological**: Recreation, tourism, ecological/habitat	**Cyprus**: Kouris Catchment. Swanson et al (2001)