INTRODUCTION TO CONCEPT, PRINCIPLES AND APPLICATIONS OF ECOHYDROLOGY

Presentation

At

WORLD RIVERS DAY/RIVER ETHIOPE FESTIVAL WEEK, 2023

RETFON-UNESCO RC-IRBM ECOHYDRLOGY CAPACITY BUILDING PROGRAMME

by

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Outline of Presentation

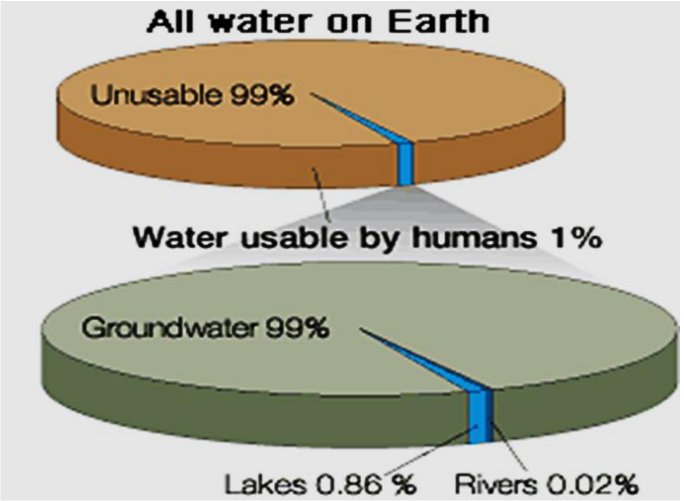
- Introduction
- River Basin Management Issues
- Need to Change the Paradigm to Water Management
- Need for an Integrated Approach to Water Management
- Why Ecohydrology?
- Understanding Ecohydrology (EH)
- Concept of EH
- EH Principles
- How EH Works
- Approach for Implementing EH
- Applications of EH
- Linking EH to Societal Livelihood
- EH and SDGs

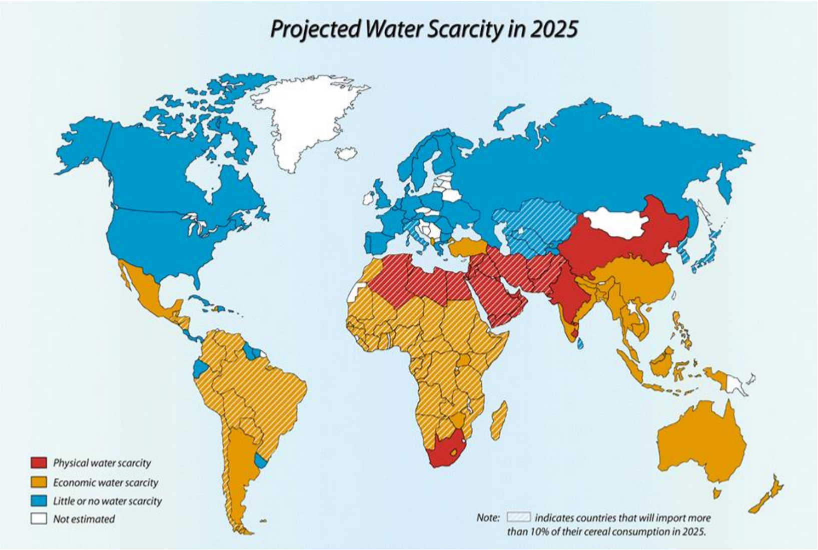
Introduction

- **The world is faced with challenges related to water resources quantity and quality;**

- **Global scenarios suggest that almost two-thirds of the world's population will experience some water stress by 2025 which will accelerate water and environmental degradation to a unimaginable scale;**

- **Consequently, provision of water for societal and environmental needs will no doubt become a major challenge toward achieving sustainable management of water resources.**





River Basin Management Issues

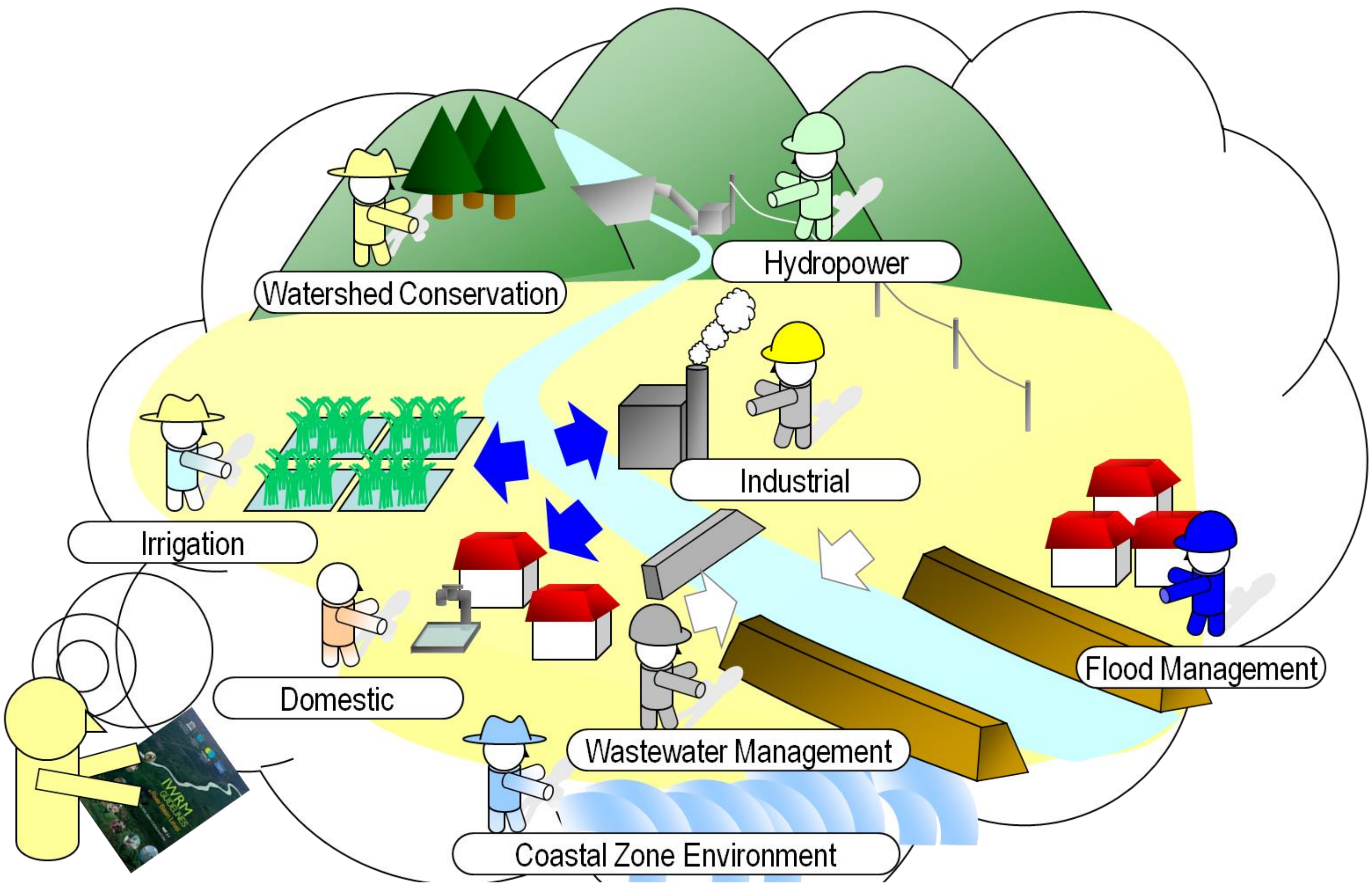
Need to Change the Paradigm to Water Management

Need to Change the Paradigm

- According to Douglas (1973), water resources management may be regarded as the modification of hydrological cycle for the benefit of mankind and the environment.
- It involves not only the beneficial uses of water resources but also the prevention, avoidance or minimization of natural effects such as flood or drought;
- Thus, to achieve ‘good water status’, both ecological and chemical and bacteriological quality of a water body need to be at least ‘good’.

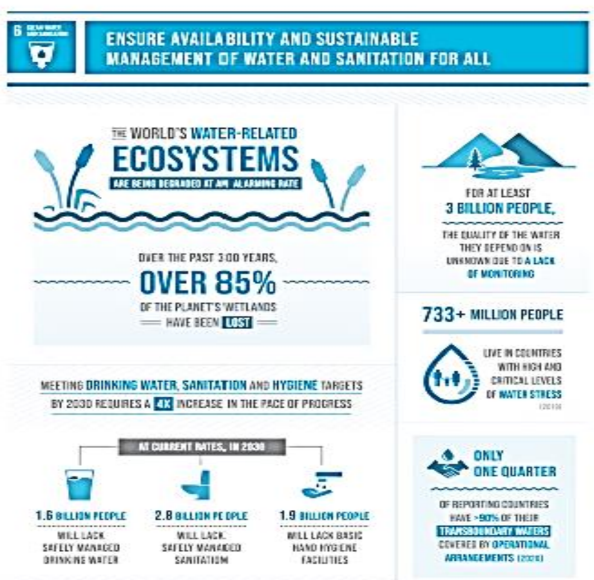
Need for an Integrated Approach to Water Management

HOLISTIC VIEW - Formulating Roadmap and Finding Priority Issue



Why Ecohydrology?

- The **decline in quality and biodiversity**, observed at the global scale in developed and developing countries, has provided **evidence that conventional approaches to water resource management**, based on application of engineering techniques, sectoral interventions and the elimination of direct threats such as point source of pollution, **are important but not sufficient**



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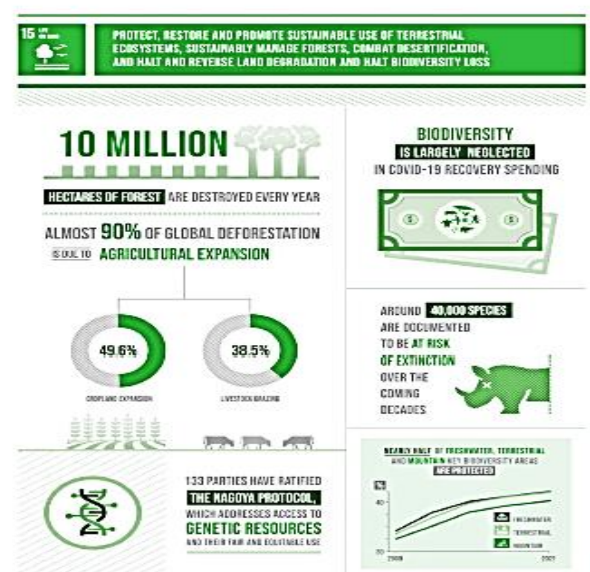

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Why Ecohydrology?...

- The development of solutions to the global challenges need to based on **trans-disciplinary approaches** recognizing **cultural and time dependent dimensions** of human wellbeing, **mitigating natural and man-induced disasters, and fostering sustainable development of cities**.

- **SO THERE IS A NEED FOR AN INTEGRATIVE SCIENCE**

Why Ecohydrology?...

New Paradigm

- This is where the emergence of Ecohydrology constitute a new dimension, and become very relevant in water resources management.

- Ecohydrology **AIMS** to find **solutions** that, rather than **focusing exclusively on technical issues**, better respond to sustainable water resource policies and **promote social development with stakeholders' participation at all levels** to make **integrated water resource management (IWRM) successful**.

Understanding Ecohydrology

What is Ecohydrology?

Defining Ecohydrology

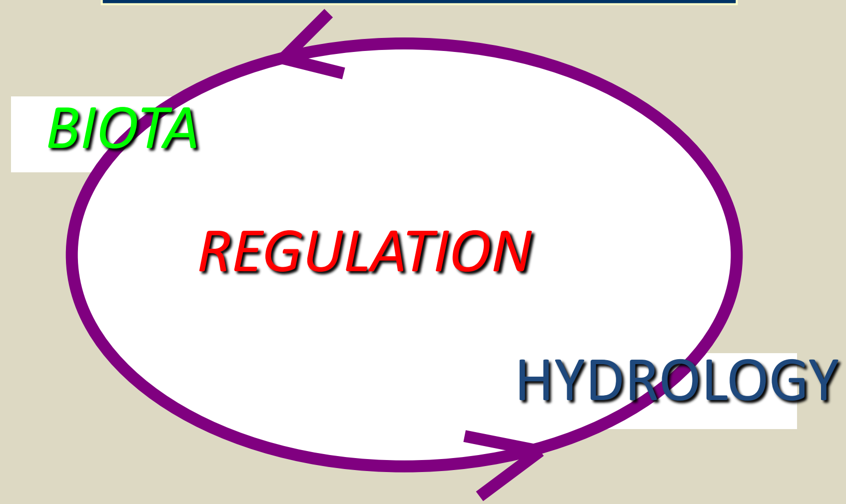
<u>Definition of Ecohydrology</u>

- *Ecohydrology (EH)* is a sub-discipline of hydrology that focuses on ecological processes occurring within the hydrological cycle, and strives to utilize such processes to enhance environmental sustainability and harmonized societal goals (Zalewski *et al.*, 1997);

- EH is an emerging integrative science that uses ecosystem properties as tools to meet water and related resources management goals.

EH Concept and Principles

"DUAL REGULATION"
Regulation of biota
by altering hydrology
and regulation of hydrology
by shaping biota



HARMONIZATION
of ecohydrological measures
with necessary hydrotechnical
infrastructure

INTEGRATION
of various regulations acting in a
synergistic way to stabilize and improve
the quality of water resources

Principles of EH

The Hypotheses of EH

The principles of EH as a framework for scientific investigation and problem solving are:

i. The Hydrological Principle;
ii. The Ecological Principle;
iii. The Ecotechnological Principle.

Principles of EH…

<u>H1: The Hydrological Principle</u>

- "The regulation of hydrological parameters in an ecosystem or catchment can be manipulated in order to control biological processes".

- The quantification and integration of hydrological and biological processes at the basin scale is based on the assumption that abiotic factors are of primary importance and become stable and predictable when biotic interactions start to manifest themselves (Zalewski and Naiman, 1985).

Principles of EH…

H2: The Ecological Principle

- “The shaping of the biological structure of an ecosystem(s) in a catchment can be achieved by regulating hydrological processes”.

- The ecological principle is based on the assumption that, under intensive global changes, it is not enough to protect ecosystems against increasing human population and aspirations. It is necessary to regulate ecosystem structure and processes towards increasing their ‘carrying capacity’ (water quality, restoration of biodiversity, ecosystem services for society, resilience of a river ecosystem).

Principles of EH…

H3: The Ecotechnological Principle

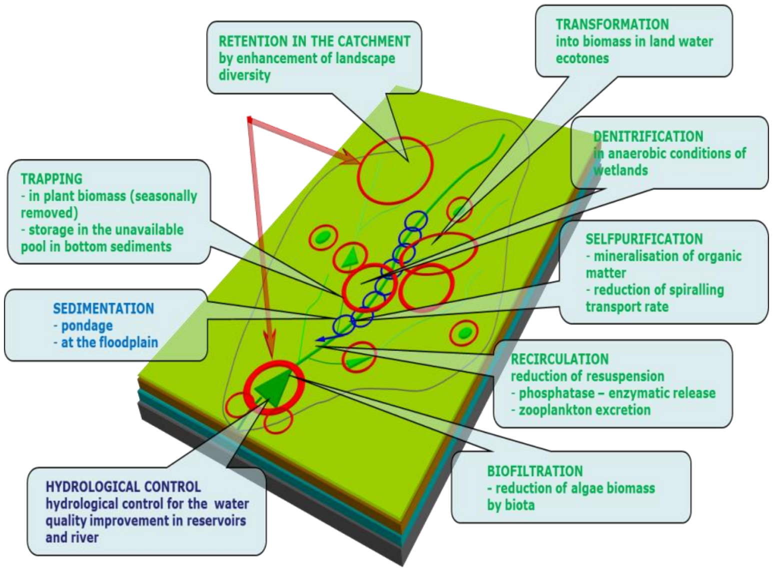
- “Both types of regulation integrated at a catchment scale in a synergistic way can be used to achieve sustainable management of freshwater resources.
- The use of ecosystem properties as a management tool is based on the first and second principles of EH. This principle features three steps of implementation:

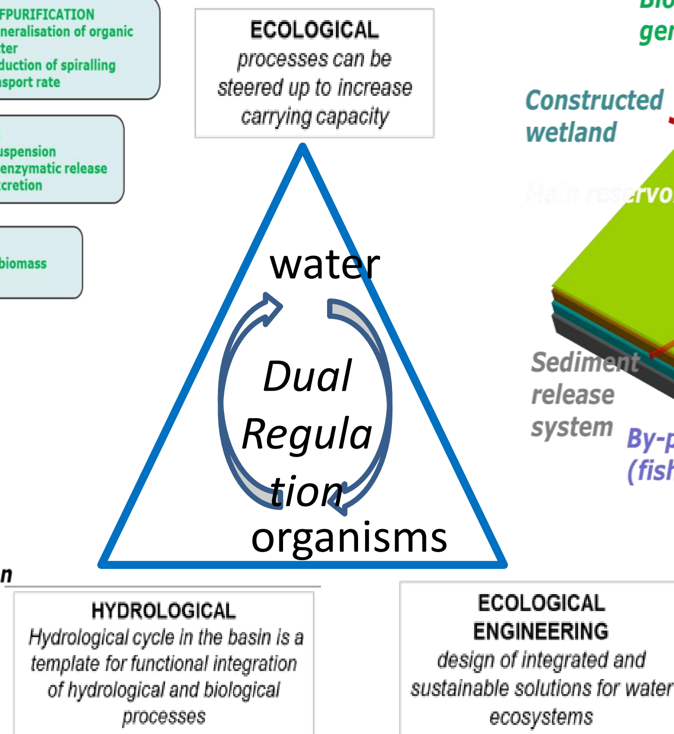
  (a) ‘dual regulation’ – biota shaping hydrology and, vice versa;

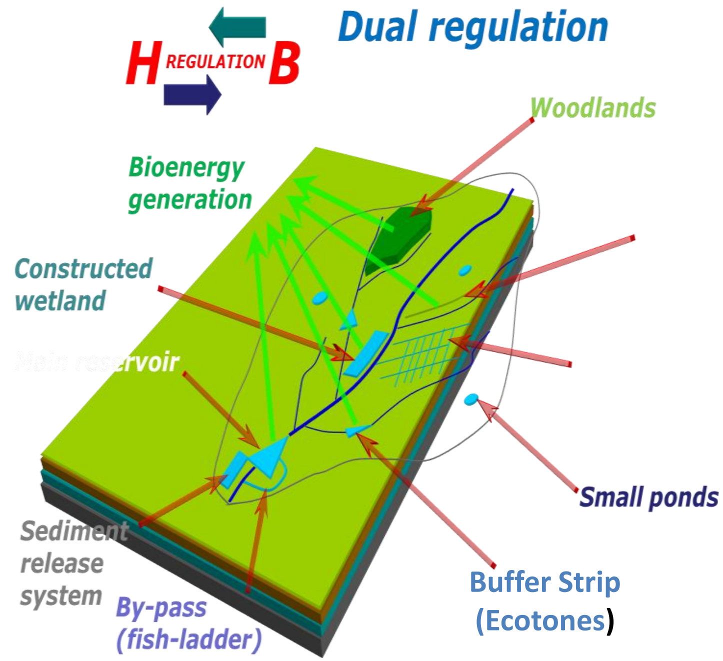
  (b) integration at basin scale of various biological and hydrological regulations towards achieving synergy in order to improve water quality, biodiversity and freshwater resources;

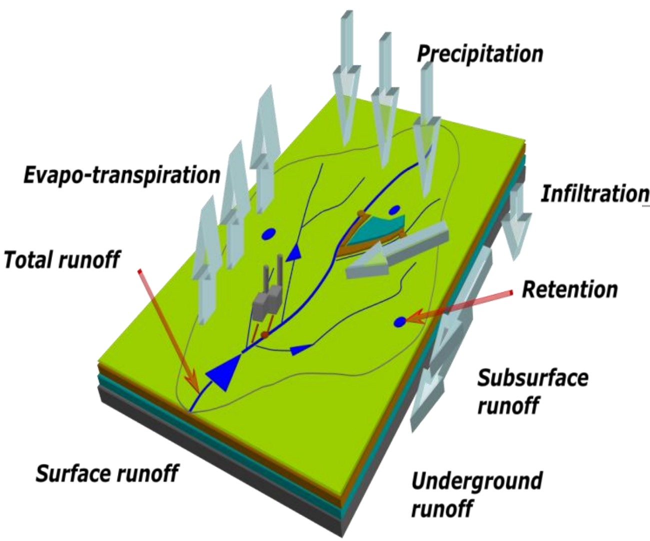
  (c) harmonisation of ecohydrological measures with necessary hydrotechnical solutions (dams, irrigation systems, sewagetreatment plants, etc.).

How EH Works



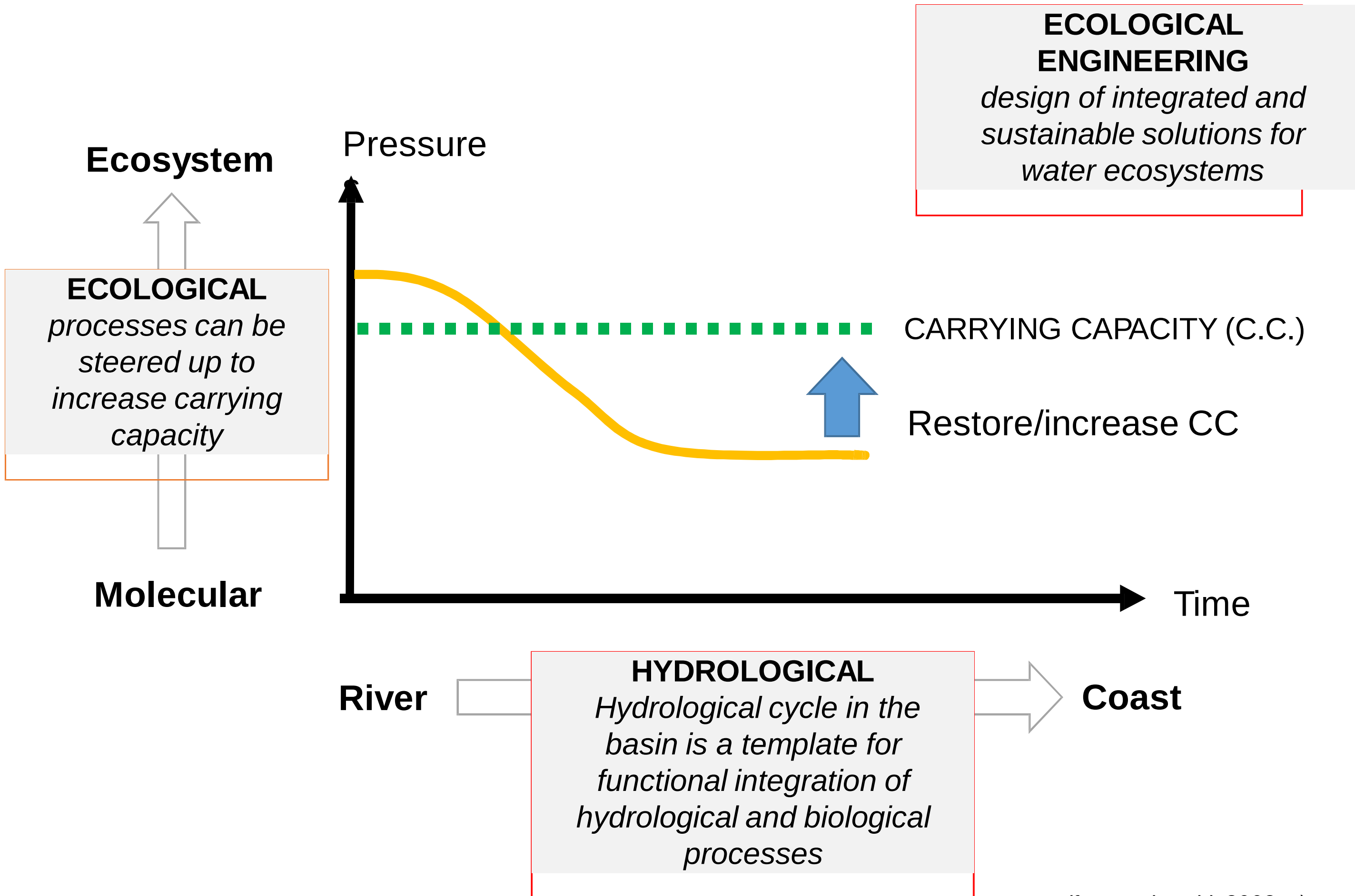






Adapted from Zalewski, 2000

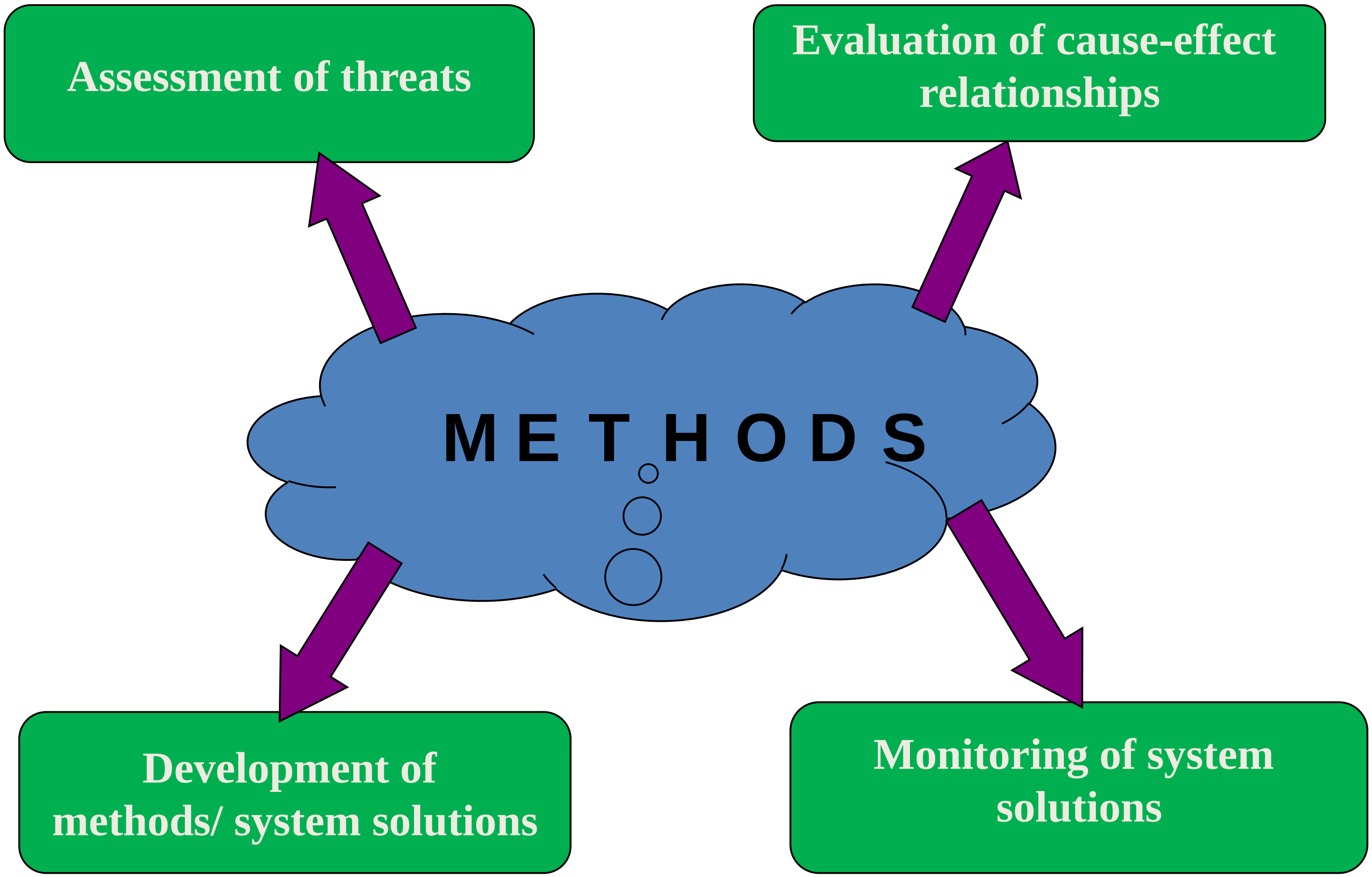
How EH Works…



(from Zalewski, 2002…)

Approach for Implementing EH

Approach for Implementing EH



Approach for Implementing EH…

- **Assessment of threats**
  - identification and quantification of a threat, its seasonal and/or spatial dynamics and effect on the societal systems
- **Evaluation of cause-effect relationships**
  - Quantification of cause-effect relationships to determine the threat and its causes;
  - Identification of hierarchy of factors influencing the dynamics of the threat.

Problem Identification & Analysis

Approaches for Implementing EH…

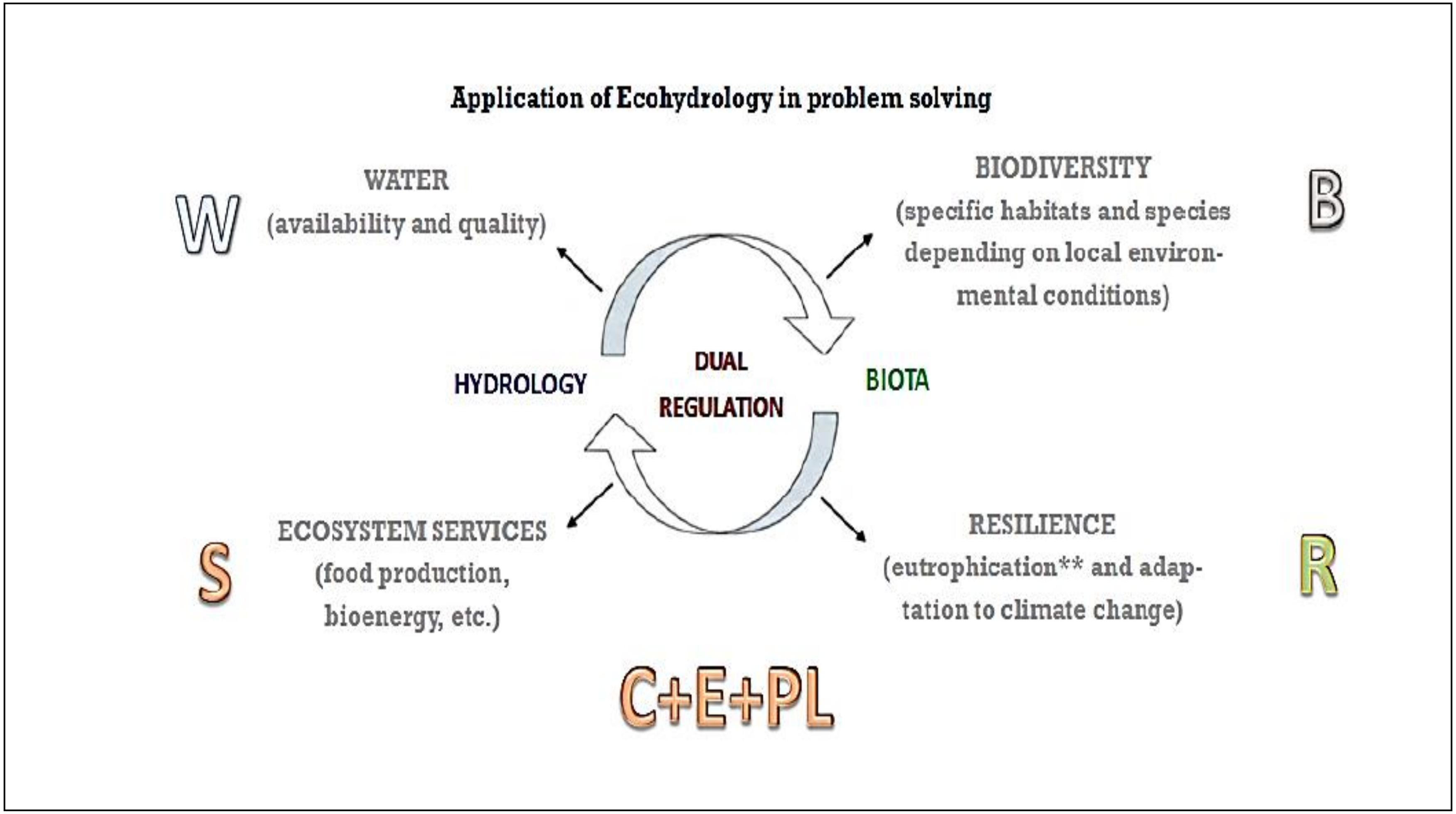
- **Development of methods/ system solutions**
  - Development of methods for:
    - control of the drivers and causes of the threat, and/or
    - control of the threat appearance.

Planning & Design

- **Monitoring of system solutions**
  - Testing and monitoring of the system solution according to EH concept;
  - Identification and evaluation of social benefits associated with the system solution.

Applications of EH

Application of EH as a Problem Solving Science



EH for Managing Water Quality

EH approaches are gaining recognition as measures to be utilized in water resources management particularly in Europe (e.g Poland, Spain etc) and more recently in Africa (e.g Kenya, Ethiopia, etc). Some of the notable applications include:

i. Restoration of eutrophic reservoir for water supply;
ii. Controlling nutrients flux into water bodies;
iii. Improving water quality.

Applications of EH: Control of Algal Bloom

Use of Hydro-Biomanipulation in controlling algal blooms

(Case of Sulejow Reservoir, Poland)

Triggers of Algae and Cyanobacterial Bloom

The cyanobacterial bloom formation depends on many physico-chemical parameters whose optimal values and coincides with the threshold values for the process of eutrophication. These parameters include:

- Water temperature (18-25°C);
- pH (6-9), nutrient availability;
- Total nitrogen (TN) above 1.5 mg/L;
- Total phosphorus (TP) above 0.1 mg/L;
- Ratio TN/TP equal or below 15/1;
- Slow current velocity;
- Long retention time; and
- Chlorophyll *a* (Chl *a*) above 10 µg/L indicates conditions for growth of cyanobacteria.

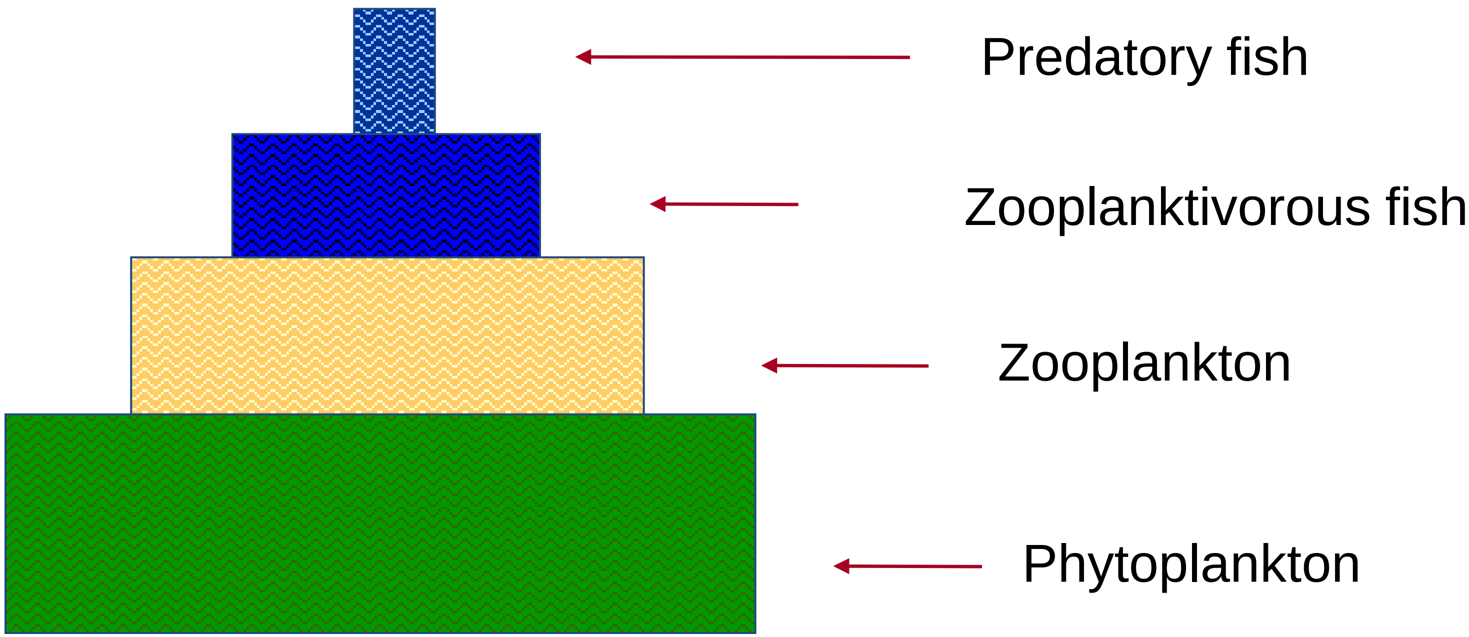
Consequences of Algal Bloom: Occurrence Cyanobacterial Toxins

TABLE 1. Cyanobacterial toxins: their function and mechanism of action (according to Chorus and Bartram, 1998; Falconer, 1999; Chorus et al., 2000; modified)

Toxin	Primary target organ in mammals	Taxon	Mechanism of toxicity
HEPATOTOXINS			
microcystins	Liver	*Microcystis, Oscillatoria/ Planktothrix, Nostoc, Anabaena*	Inhibition of protein phosphatase activity, hemorrhaging of the liver
nodularins	Liver	*Nodularia*	
CYTOTOXINS			
cylindrospermopsins	Liver, kidney, spleen, intestine, heart, thymus	*Cylindrospermopsis, Umezakia*	Inhibition of protein synthesis
NEUROTOXINS			
anatoxin-a	Nerve synapse	*Anabaena, Oscillatoria, Aphanizomenon*	Blocking of post-synaptic depolarization
anatoxin-a(s)	Nerve synapse	*Anabaena*	Blocking of acetylcholinesterase
saxitoxins	Nerve axons	*Aphanizomenon, Anabaena*	Blocking of sodium channels
neosaxitoxins	Nerve axons	*Aphanizomenon, Anabaena*	
DERMATOTOXINS			
lungbyatoxins-a	Skin	*Lungbya*	Protein kinase C activators, inflammatory activity
debromoaplysiatoxins	Skin	*Lungbya*	
aplysiatoxins	Skin	*Lungbya, Schizothrix, Oscillatoria*	
IRRITANT TOXINS			
lipopolysaccharides	Any exposed tissue	All	Potential irritant and allergen

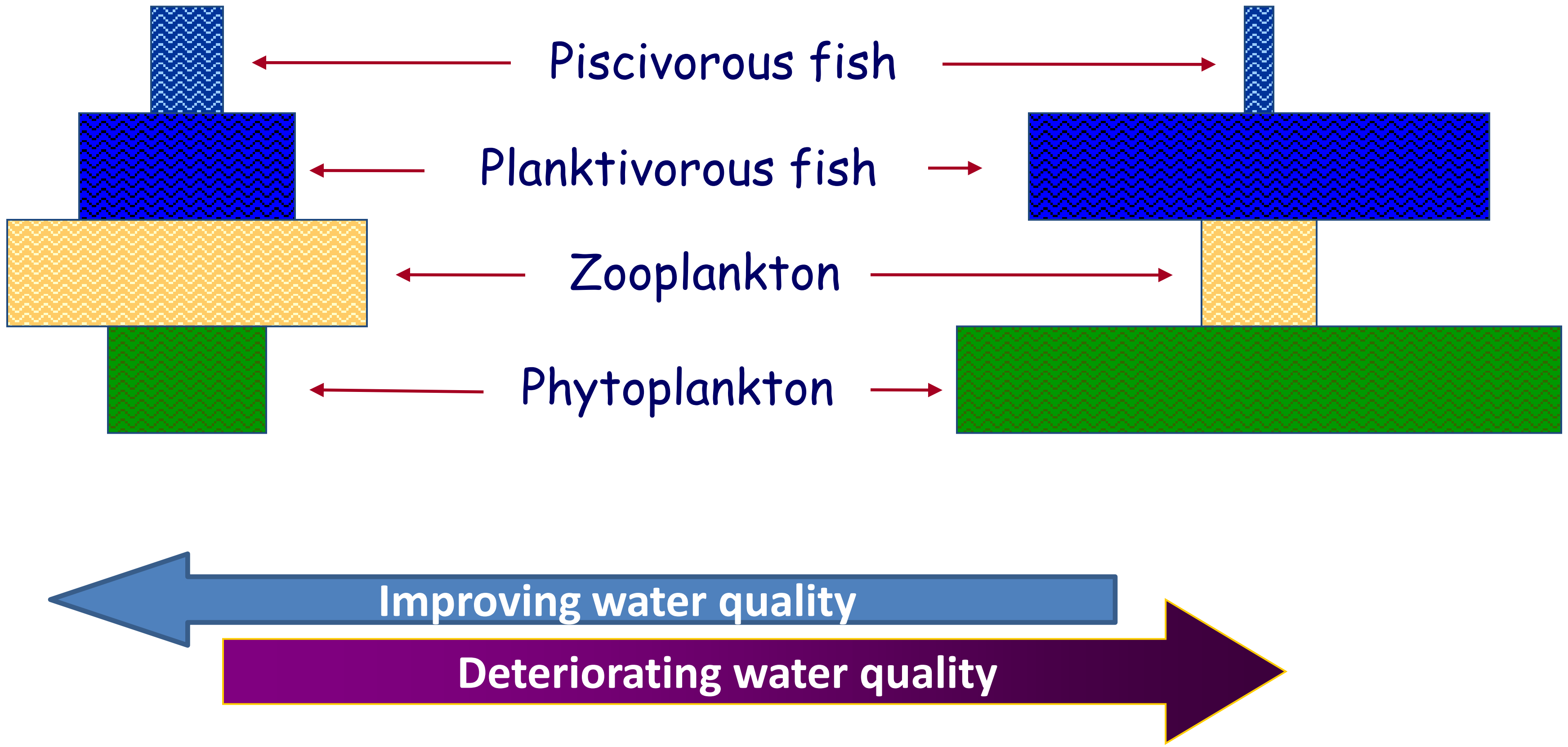
Applications of EH: Control of Algal Bloom…

Classical trophic pyramid



Applications of EH: Control of Algal Bloom…

Cascading effect in trophic pyramid



Applications of EH: Control of Algal Bloom…

Before application of EH

After application of EH

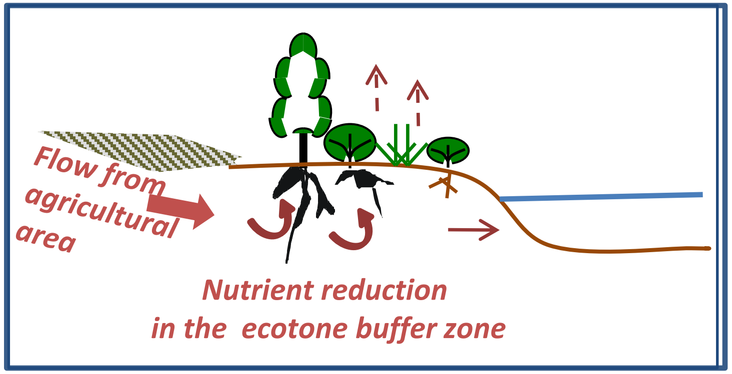
However, manipulation of biotic structure towards controlling of algal blooms requires understanding and quantification of trophic interactions, which are greatly ecosystem-specific.

Applications of EH: Control of Nutrients Flux to Water Bodies

Use of ecotones in reducing nutrient flux to water body and controlling algal bloom

Ecotone

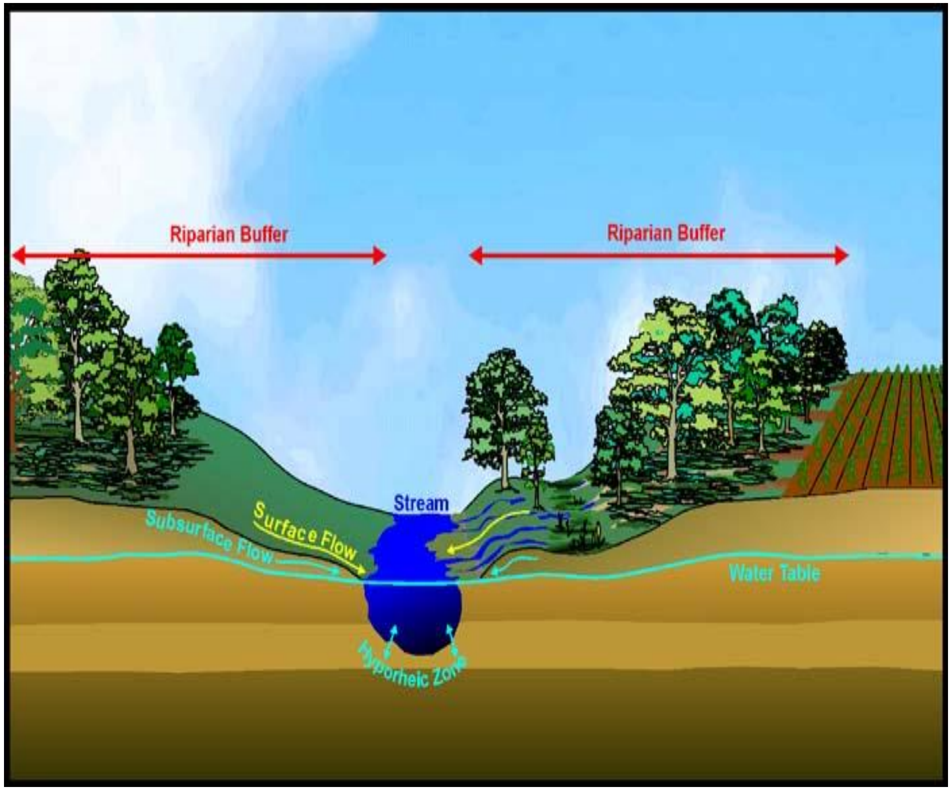
- Ecotone is a transition area between two biomes and different patches of the landscape, such as land and water or forest and grassland.
- It may be narrow or wide, and it may be local (the zone between a field and forest) or regional (the transition between forest and grassland ecosystems).



Applications of EH: Control of Nutrients Flux to Water Bodies

Ecotones as Riparian Buffer Zones

- Lands adjacent to rivers, streams, lakes and wetlands
- Lands at the margins of municipal reservoirs



Ecological Functions of Ecotones

- Improve water quality by trapping sediment and chemicals from runoff before reaching water bodies;
- Moderates flooding, help recharge groundwater and prevent soil erosion;
- Create shade which lower water temperatures and hence improve habitat for aquatic organisms;
- Provide a source of woody debris for aquatic and terrestrial organisms;
- Provide food, nesting cover and shelter that enable wildlife to move safely from one habitat to another;
- Increase carbon storage.

Applications of EH: Control of Nutrients Flux to Water Bodies

Before application of EH

After application of EH

Applications of EH: Control of Nutrients Flux to Water Bodies…

Use of Denitrification wall for control of nutrient flux

- Denitrification wall is constructed by digging a trench perpendicular to groundwater flow and mixing sawdust with soil.

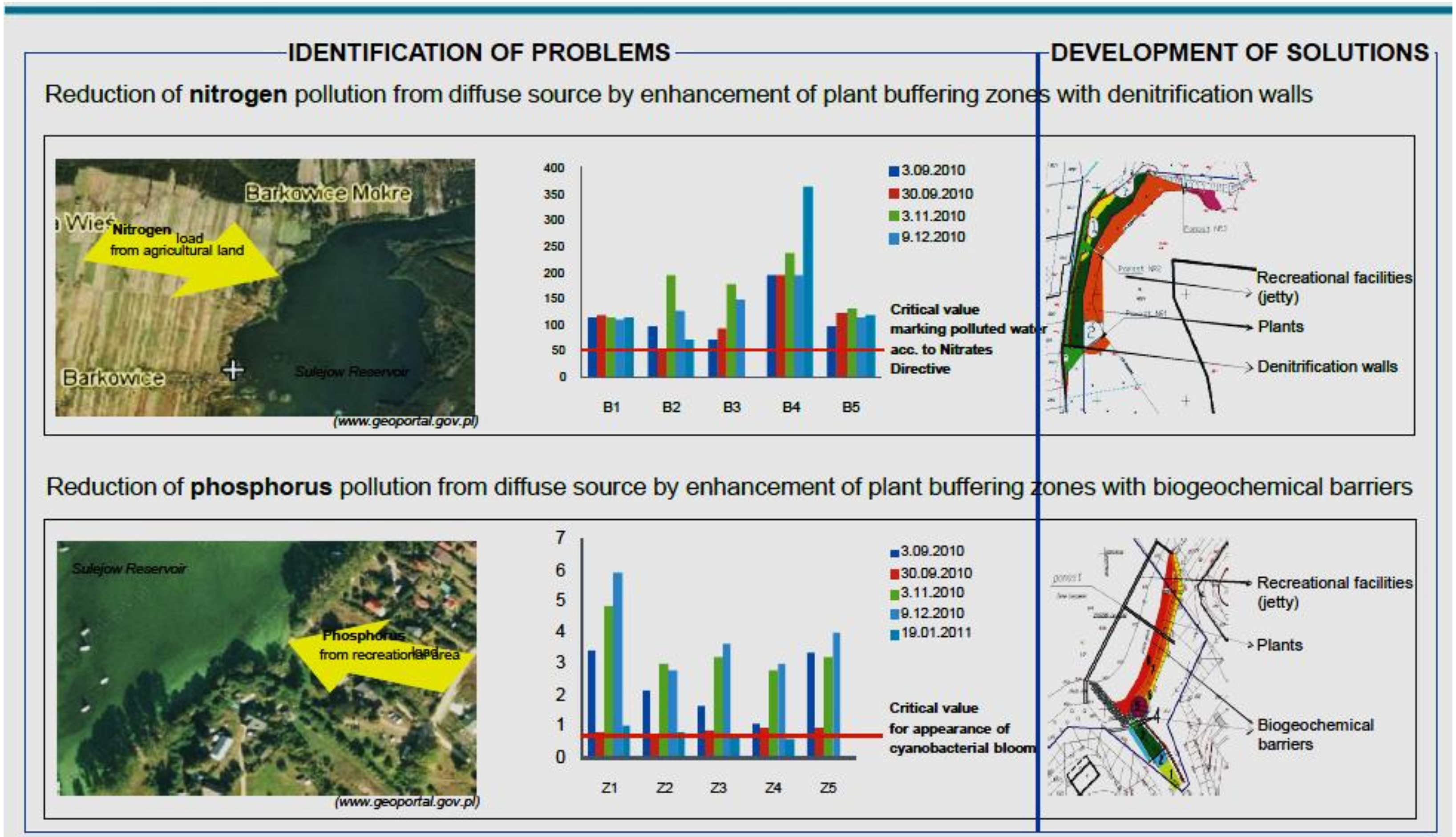
- Degradation of added organic material stimulates growth of denitrifing bacteria, thus conversion of nitrate to nitrogen gas by denitrification occurs.

- After the construction work, the wall is not visible.

Applications of EH: Control of Nutrients Flux to Water Bodies…

Construction of Denitrification Wall

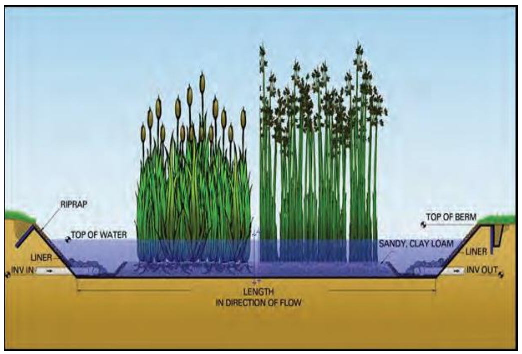
Applications of EH: Control of Nutrients Flux to Water Bodies…



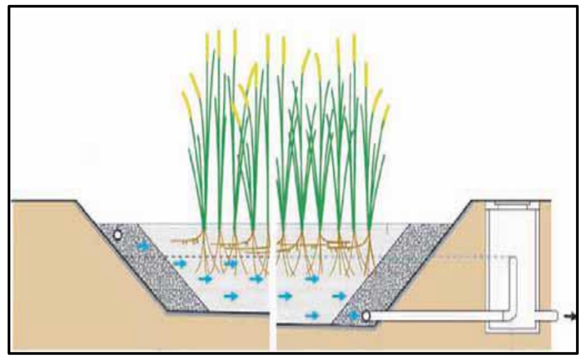
Use of ecotones combined with denitrification wall and biogeochemical barriers for reduction of diffuse pollutions (LIFE + EKOROB Project)

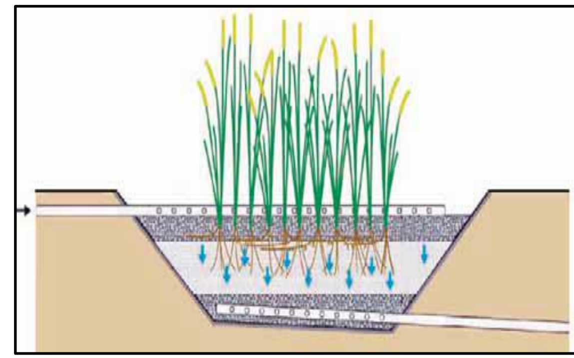
Applications of EH: Improving Water Quality…

Constructed wetlands types

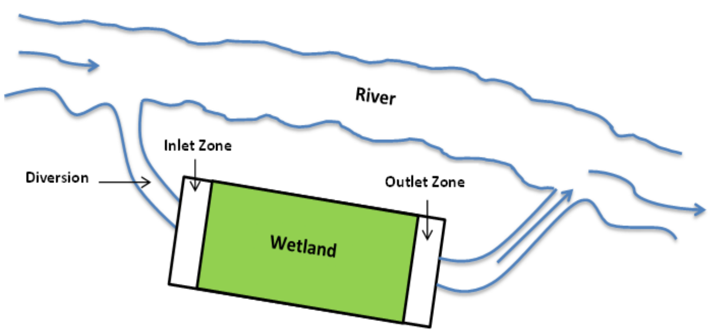


Free Surface flow wetlands

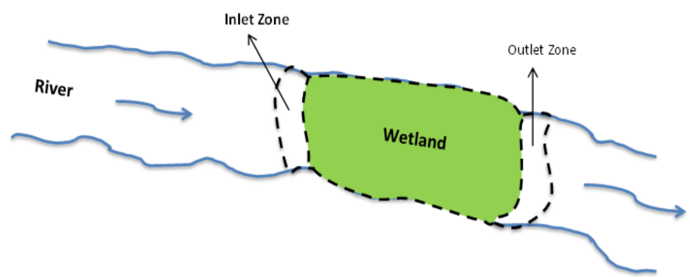




Sub-surface flow wetlands



Off-stream river diversion wetland



In-stream river diversion wetland

River Diversion Wetlands

Applications of EH: Improving Water Quality…

System under construction   System in operation

Sequantial Stormwater Purification System for Sokołówka river catchment(City of Łodz)

Applications of EH: Improving Water Quality…

Figure 5: Layout of the model constructed river diversion wetland

Applications of EH: Improving Water Quality …

Use of constructed river diversion wetland

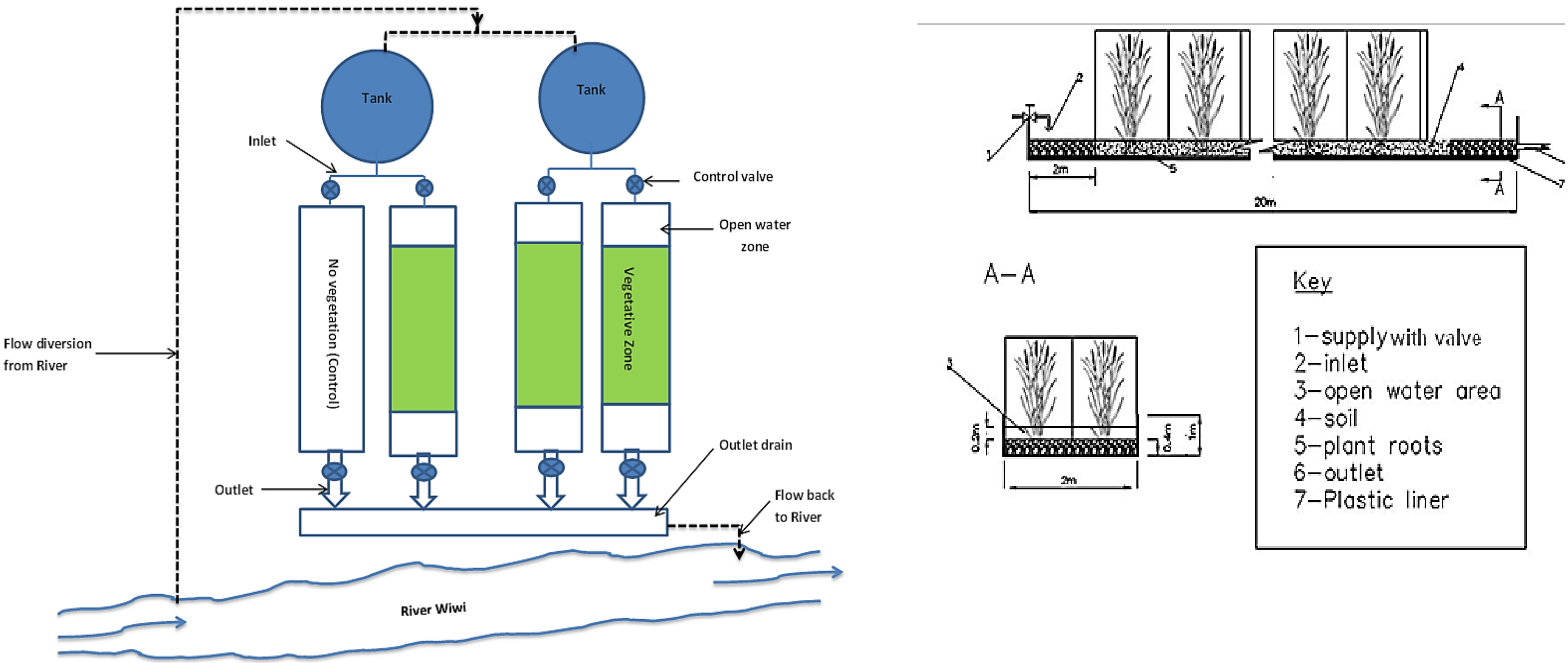
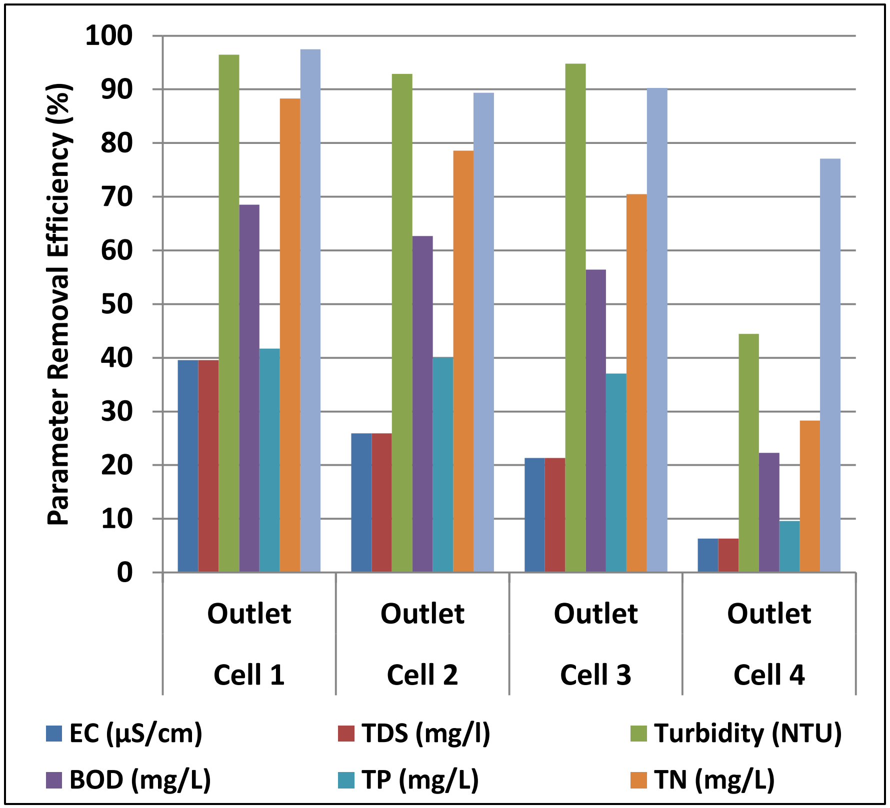
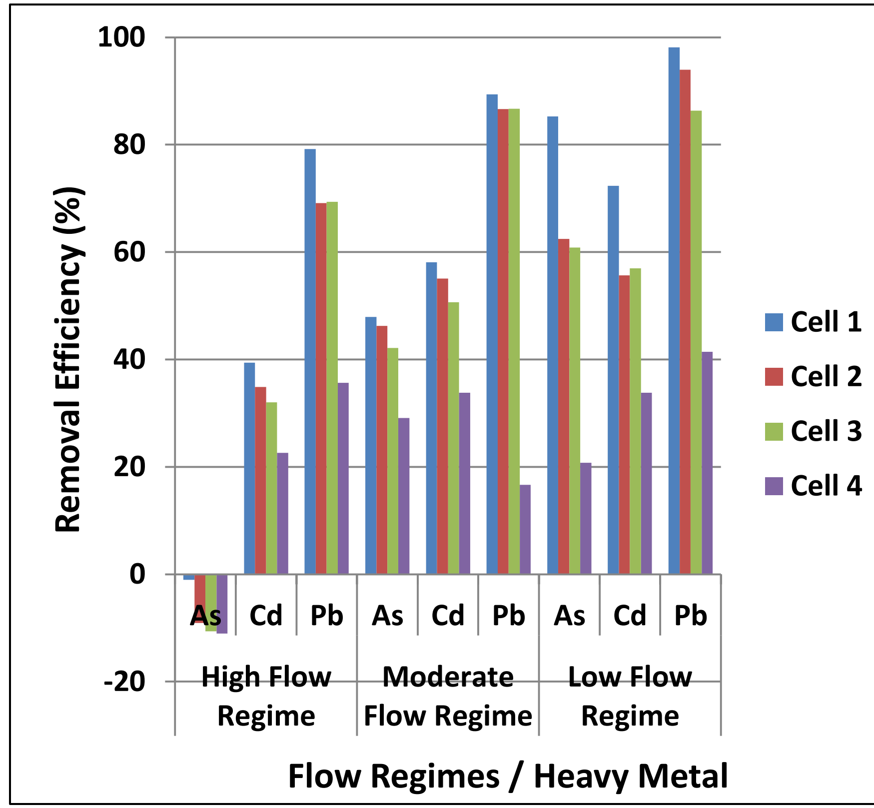


Figure: Schematic layout of the model constructed river diversion wetland

Applications of EH: Improving Water Quality…





Performance of constructed model river diversion wetland for improving water quality

EH for Managing Water Quantity

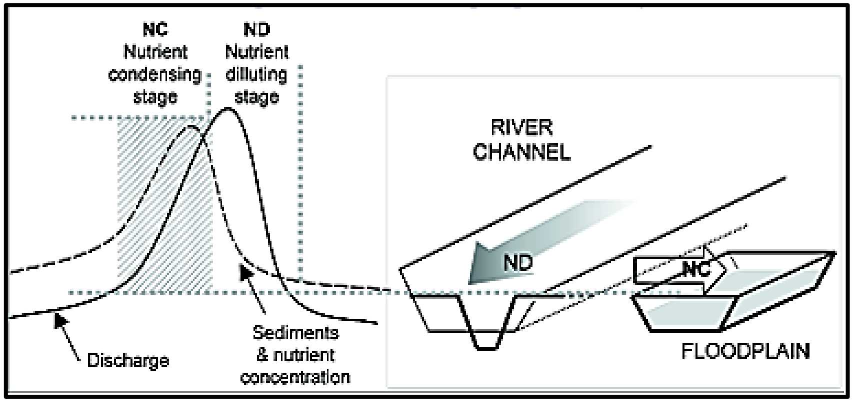
- EH solutions address water availability (supply or quantity) through managing:
  - precipitation and humidity;
  - water storage;
  - infiltration and overland flow.

- In many cases, more ecosystem-friendly forms of water storage have been found to be more sustainable and cost-effective such as
  - natural wetlands,
  - improvements in soil moisture and
  - more efficient recharge of groundwater

Water Management Issue	EH Potential Solution	Location		
		Watershed	Floodplain	Urban
Water availability regulation	Re/afforestation and forest conservation			
	Reconnecting rivers to floodplain			
	Wetland restoration/ conservation			
	Constructing wetlands			
	Retention ponds (bioretention and infiltration systems)			
	Water harvesting			

EH for Managing Water Quantity: Restoration of Floodplains

- Floodplains are natural, self-sustaining systems where purification processes and water retention are driven by natural forces;
- They play a double role as both water quality and quantity improving tools;
- They can hold up to 1.5 million gallons of floodwater per acre;
- Preservation of natural and restoration of degraded floodplains improves the quality of water and stabilizes hydrological parameters of rivers.



EH for Managing Water Quantity: Use of Infiltration Basin

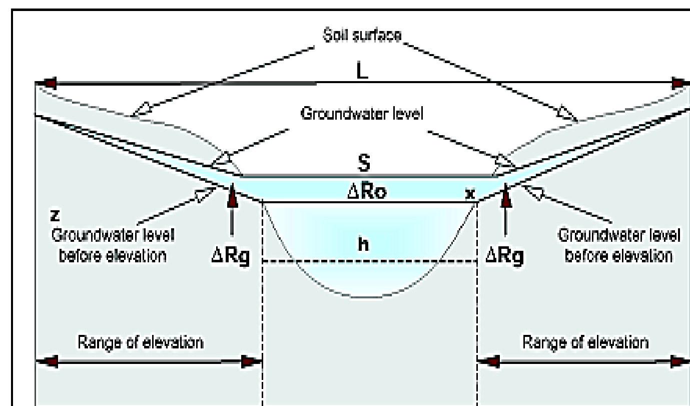
Detains storm water above ground which then soaks away into the ground through the base

EH for Managing Water Quantity: Use of Water Retention Ponds

- Retention ponds are artificial reservoirs designed with a permanent pool of water area and may include vegetation around the perimeter in its design;

- They consist of a reservoir with storage capacity to store and treat water (e.g surface runoff during rainfall events);

- They can be designed to support emergent and submerged aquatic vegetation along their shoreline;



h – average depth of water in a pond, ΔRo - water retention in a pond, L – range of water retention increase in soil, S – pond diameter

Application of EH in the Context of Climate Change

- The recent ecohydrological strategies (e.i. WBSRC and CE+NBS) present a sustainable and evolutionary approach to the management of water-dependent ecosystems, can effectively mitigate the impact of climate change and simultaneously improve resilience and a variety of ecosystem services.

Application of EH in the Context of Climate Change…

	WBSRC Guideline for Water Resources Management
W – Water	• Increase city retentiveness (also referred as a sponge city concept) through water harvesting and retention. • Recreate hydrological cycle through cohydrological processes. • Protect water quality and enhance resilience of ecosystems with NBS. • Encourage water recycling and reuse by promoting and implementing on larger scale infiltration of water as a strategy for groundwater replenishment.
B – Biodiversity	• Consider aquatic and water-related ecosystems as a biodiversity refuge. • Encourage building of Blue-Green-Network (BGN) as a system of ecological corridors and nature-protected areas. • Protect aquatic ecosystems through the use of NBS. • Recreate habitats with gradient of conditions that favours higher biodiversity. • Increase the gene pool through NBS and Blue-Green-Infrastructure (BGI). • Make wise use of ecosystem-based vegetation management for biodiversity stimulation.

Application of EH in the Context of Climate Change…

	WBSRC Guideline for Water Resources Management
S – ecosystem Services	• Use blue-green ecosystems to stimulate human immune system, reduce the stress and increase well-being (Rook, 2013). • Encourage microclimate regulation. • Utilize local reservoirs to serves as recreational places, making a low-cost alternative for holidays for the poorest urban dwellers. • Increase air humidity to reduce the amount of particulates in air, one of a major causes of lungs damage in urban areas. • Use of Constructed Wetlands (CWs) for purification of effluent is supporting the water resources quality. However, CWs require more space, but on the same time they are using less energy, and provides other ecosystem services and aesthetic value increase in urban areas.

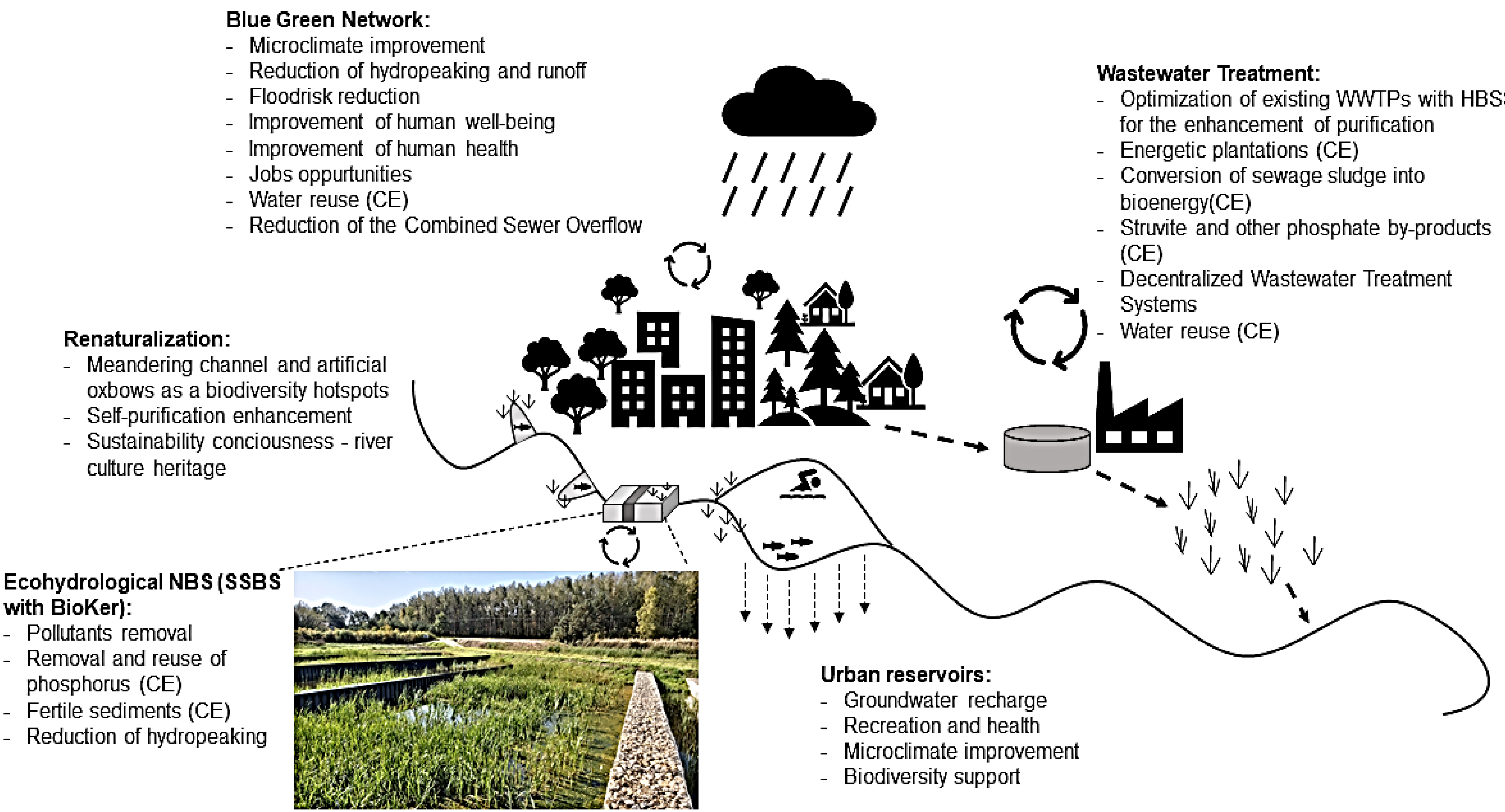
Application of EH in the Context of Climate Change…

	WBSRC Guideline for Water Resources Management
R – Resilience	• Enhance ecosystem resilience to anthropogenic and climatic stress by stabilizing water pulses and providing enough space in urban communities (at the level of fauna and flora) such as the "room for the river". • Encourage management of BGI to create additional workplaces within the city, and at the same time generating positive feedbacks. • Promote Circular Economy to provide more green economy and reduce the ecological footprint of urban society. • Encourage application of ecohydrology in the city to facilitate reduction of greenhouse gasses emission, through reduced air conditioning and temperature reduction in water reservoirs.

Application of EH in the Context of Climate Change…

	WBSRC Guideline for Water Resources Management
C – Cultural heritage and education	• Encourage use of cultural heritage for water resources protection, rehabilitation or management of aquatic ecosystems. • Build everlasting, resilient and durable environment through involvement of local societies. • Encourage local society dedication in the application of ecohydrological solutions in urban areas limited by local conditions, human-dominance, etc., for their existence and proper functioning. • Education of young generations is essential for a future maintenance of ecosystems.

Application of EH in the Context of Climate Change…

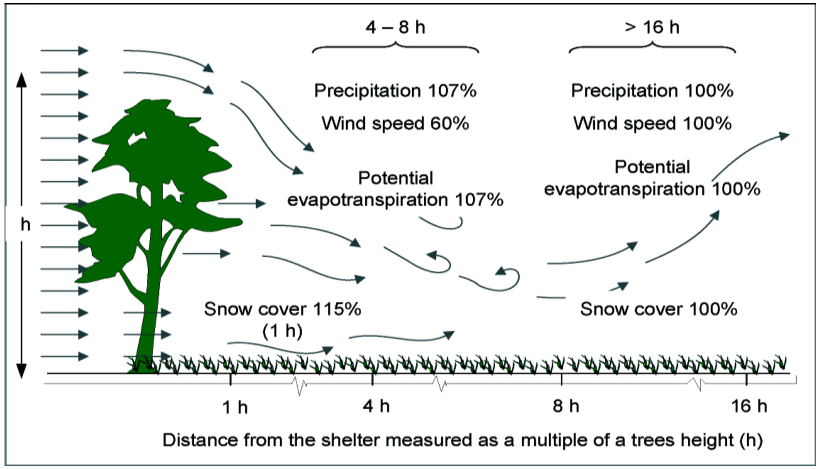


Jarosiewicz et al., 2021

Application of EH in the Context of Climate Change: Use of Shelterbelts

- Shelterbelts are linear forests consisting of shrubs and trees established on the landscape to address various conservation goals like:
  - stabilizing water circulation;
  - conserving soil moisture;
  - providing shelter from the wind;
  - protecting soil from erosion, etc.

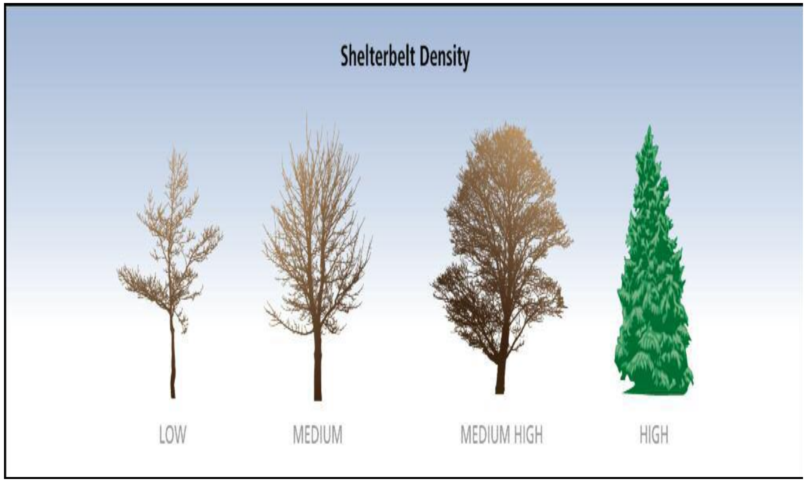
- Plant cover exert a favourable influence on microclimate by:
  - reducing wind speed by 35-40%;
  - increasing relative air humidity;
  - decreasing potential evaporation;
  - increasing snow depth; and
  - reducing the melting rate of snow in spring.

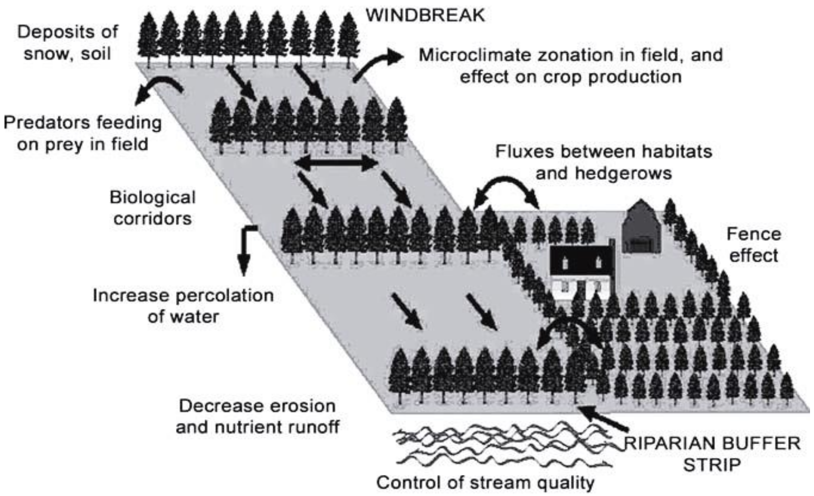


Application of EH in the Context of Climate Change: Use of Shelterbelts…

When planning for shelterbelt, it is important to keep the following considerations in mind:

- Site assessment and locate the shelterbelt where it will be most effective;
- Design the shelterbelt to fit the available space and to meet your objectives. The design must take into account proper spacing to allow for good density and optimum tree growth and the use of maintenance equipment;
- Select tree and shrub species that are well adapted to your soil and climatic conditions;
- Provide care and protection for young seedlings;
- Control weeds after shelterbelt establishment.





Application of EH in the Context of Climate Change…

Contribution of EH to Climate change Resilience Dimensions

NBS = nature-based solutions.

Source: Adapted from X. Lu. 2019. Building Resilient Infrastructure for the Future: Background Paper for the G20 Climate Sustainability Working Group. *ADB Sustainable Development Working Paper Series.* No. 61. Manila: Asian Development Bank.

Application of EH: Linking EH to Societal Livelihood

- Identification of solutions to threats (proliferation of water hyacinth) in the Lake ecological systems

Application of EH: Linking EH to Societal Livelihood…

- Conversion of threats to opportunities and linking EH to societal livelihood.

EH and SDGs

- **Biodiversity** (**Goals 14** life below water **and 15** life on land) and
- **Water** (**Goal 6**) are key ingredients for sustainable development, which cuts across several of the sustainable development goals of the **2030 Agenda**.

Thank You For Listening