





September 10,
2025

Ecological Engineering and Wetland Ecosystem Creation and Restoration

Robert W. Nairn, PhD, BCES

Robert W. Hughes Centennial Professor of Engineering

David L. Boren Distinguished Professor

Viersen Family Foundation Presidential Professor

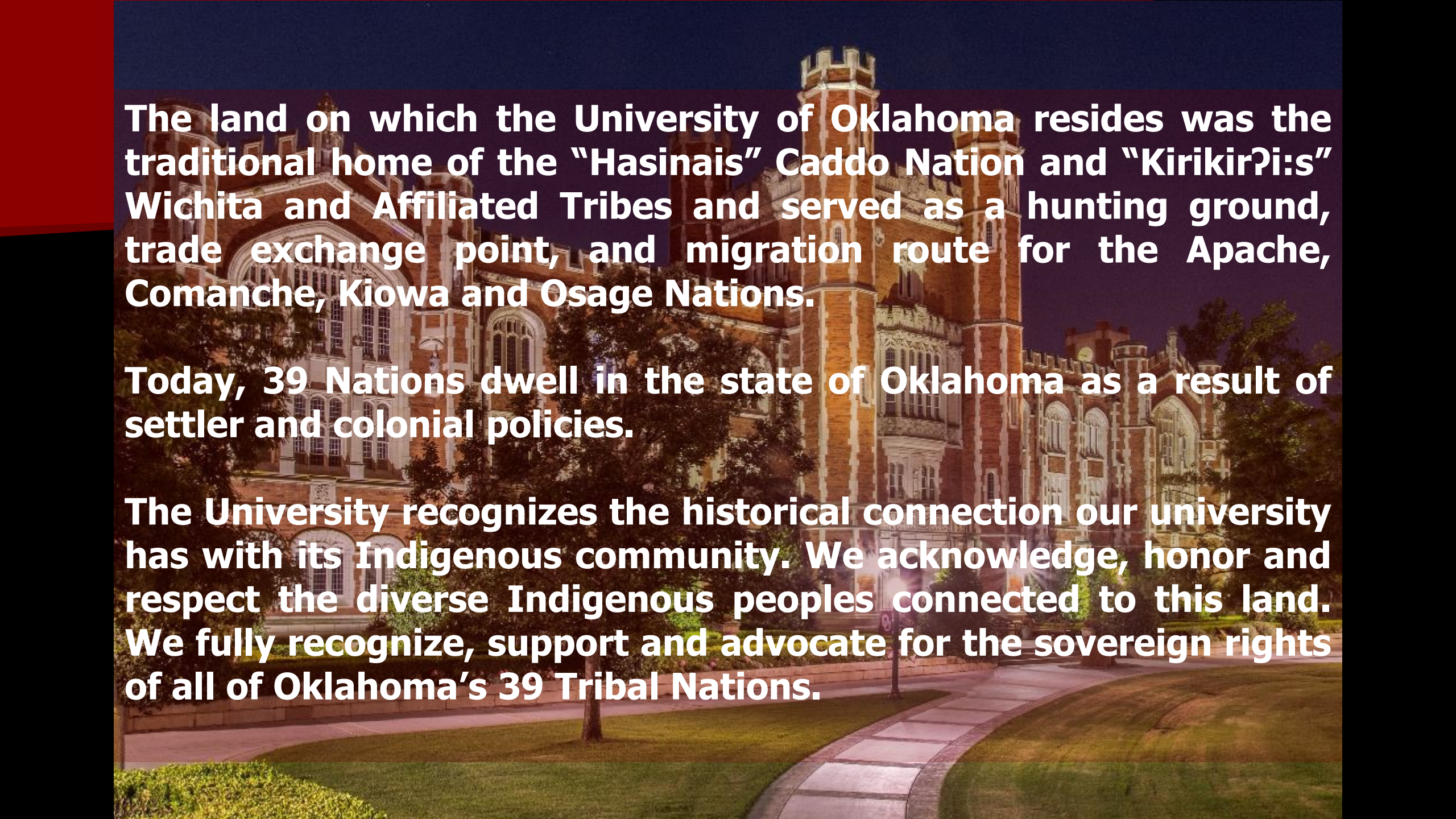
The University of Oklahoma



GALLOGLY COLLEGE OF ENGINEERING
**SCHOOL OF CIVIL ENGINEERING
AND ENVIRONMENTAL SCIENCE**
The UNIVERSITY of OKLAHOMA



CREW
Center for Restoration of
Ecosystems and Watersheds
The University of Oklahoma



The land on which the University of Oklahoma resides was the traditional home of the “Hasinai” Caddo Nation and “Kirikir?i:s” Wichita and Affiliated Tribes and served as a hunting ground, trade exchange point, and migration route for the Apache, Comanche, Kiowa and Osage Nations.

Today, 39 Nations dwell in the state of Oklahoma as a result of settler and colonial policies.

The University recognizes the historical connection our university has with its Indigenous community. We acknowledge, honor and respect the diverse Indigenous peoples connected to this land. We fully recognize, support and advocate for the sovereign rights of all of Oklahoma’s 39 Tribal Nations.



Untreated artesian mine water flows,
Tar Creek Superfund Site



Passive treatment system discharge

Environmental Problem Solving

- Conventional technological approaches
 - Anthropocentric solutions
 - Energy and nonrenewable-resource intensive
 - “The Shell Game”



Environmental Problem Solving

- Innovative sustainable solutions
 - Work with (*not against*) natural processes
 - Use renewable energy and resources
 - Partner with Mother Nature and Father Time



+



=



Sustainable
Solutions

The Need is Obvious

- Population growth
- Resource limitations
- Freshwater scarcity
- Energy demand
- Climate change

- A (more) sustainable future?



World population growth, 1700-2100

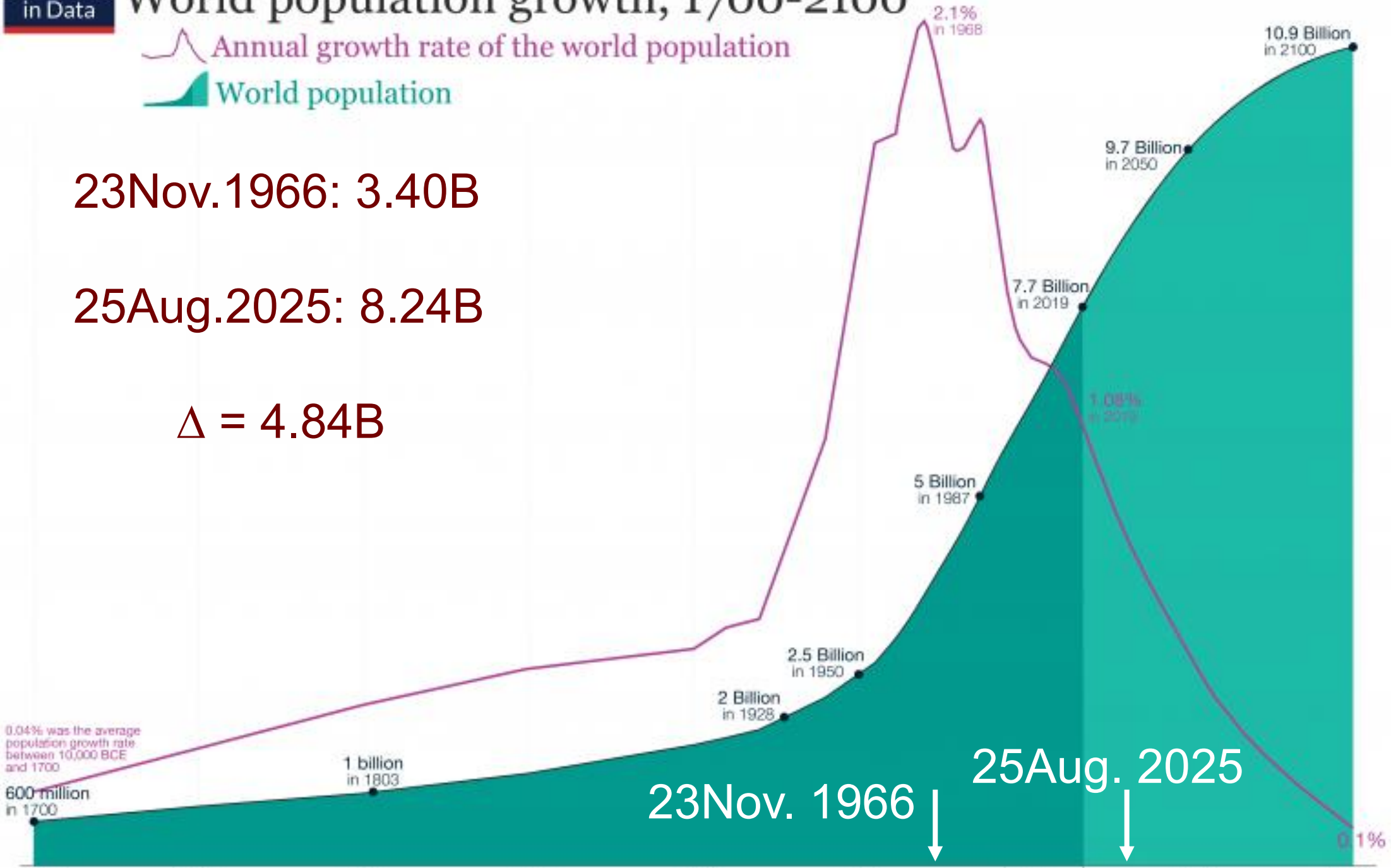
Annual growth rate of the world population

World population

23Nov.1966: 3.40B

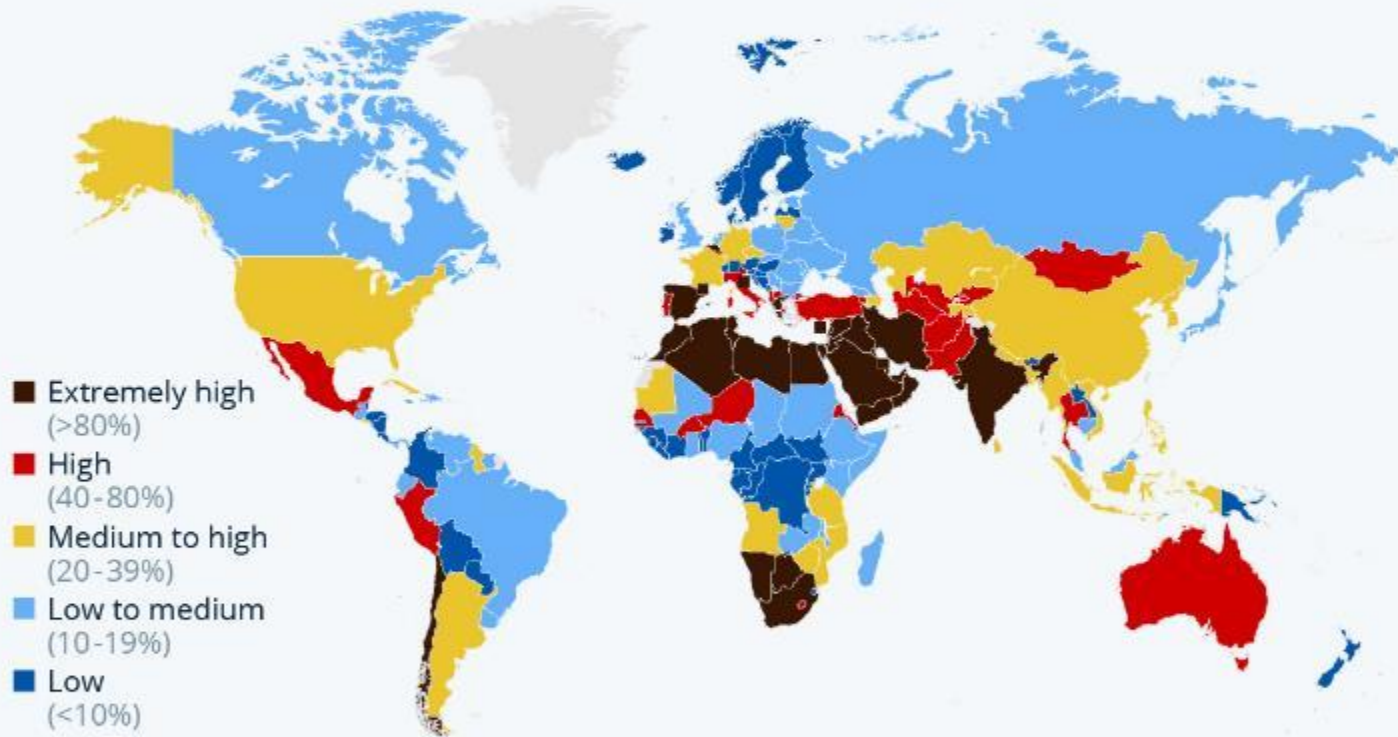
25Aug.2025: 8.24B

$$\Delta = 4.84B$$



Where Water Stress Will Be Highest by 2050

Projected ratio of human water demand to water availability (water stress level) in 2050*



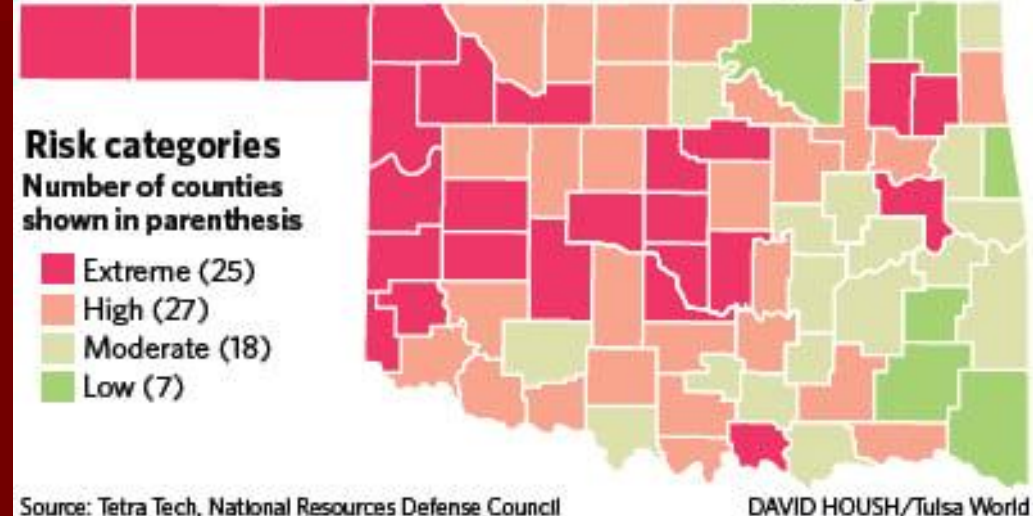
* According to "business as usual" scenario=middle-of-the-road future where temperatures increase by 2.8°C to 4.6°C by 2100

Source: World Resources Institute



Water Scarcity

Oklahoma counties at risk of water shortage by 2050

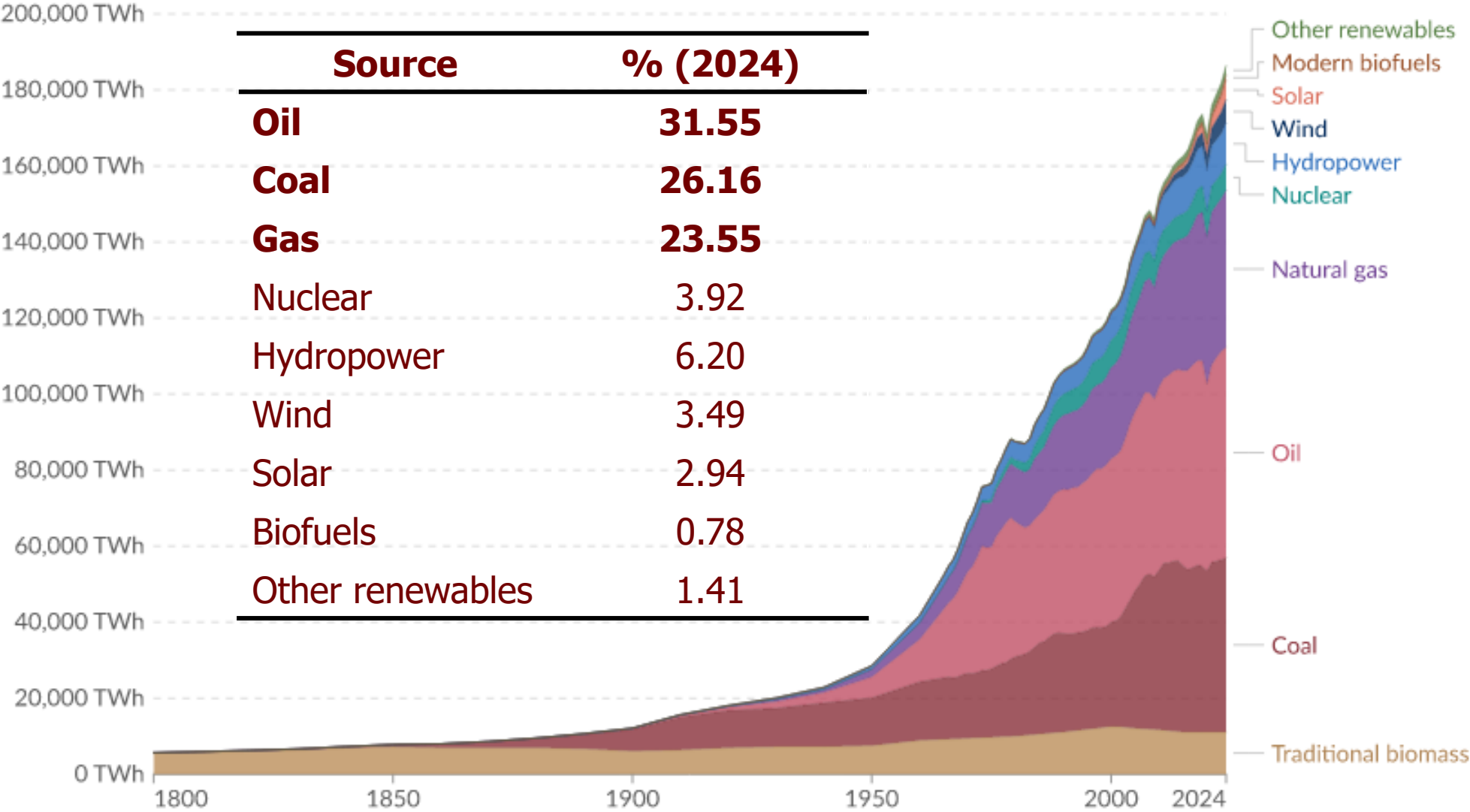


■ *Human* water demand to water availability

■ No recognition of ecosystem needs

Global primary energy consumption by source

Primary energy is based on the substitution method and measured in terawatt-hours.

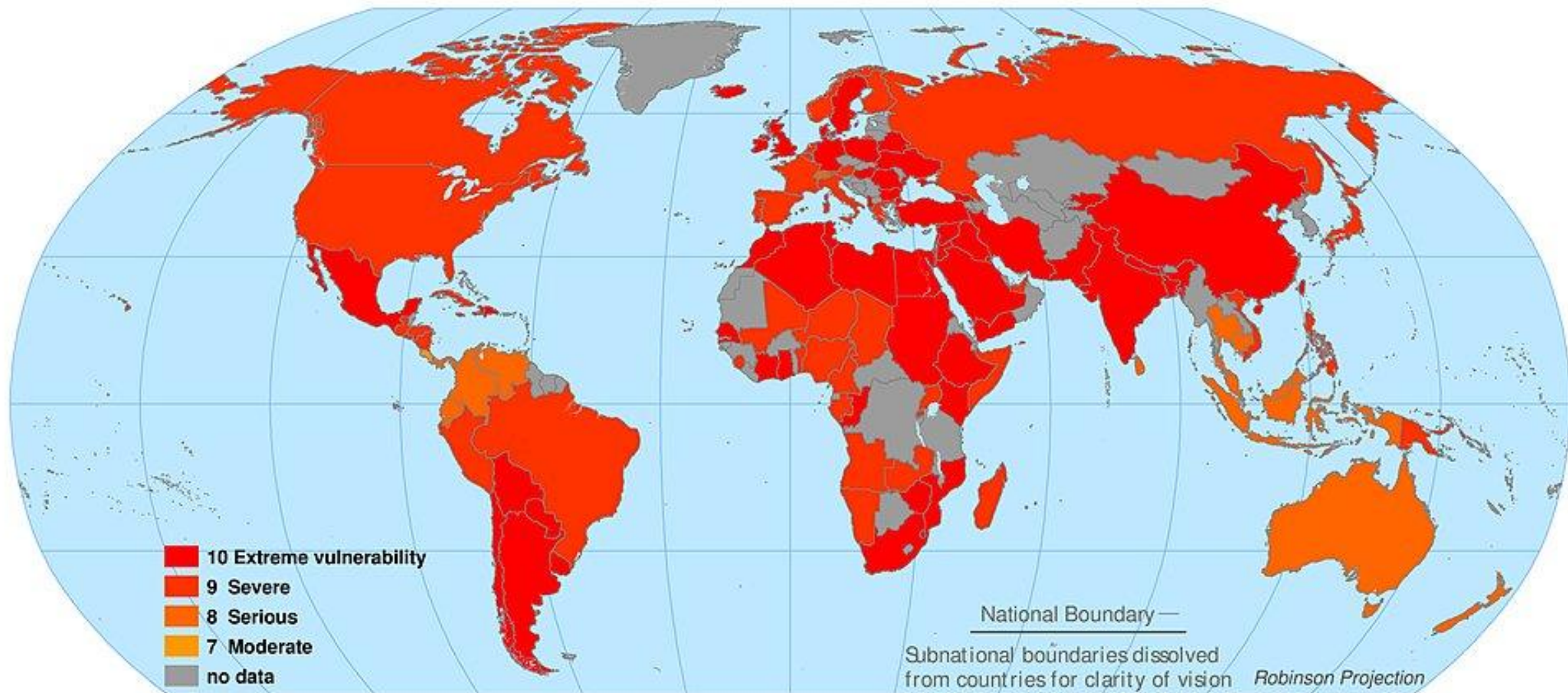


Data source: Energy Institute - Statistical Review of World Energy (2025); Smil (2017)

Note: In the absence of more recent data, traditional biomass is assumed constant since 2015.

Global Distribution of Vulnerability to Climate Change

Combined National Indices of Exposure and Sensitivity



Scenario A2-550 in Year 2100 with Climate Sensitivity Equal to 5.5 Degrees C
Annual Mean Temperature with Extreme Events Calibration and Enhanced Adaptive Capacity

Ecological Engineering?

Ecology

- “Study” of our “house”
- Relationships between organisms and environment
- Descriptive science



Engineering

- Application of science to meet societal needs
- Design-oriented
- Prescriptive solutions



Can we marry ecology and engineering?



**Ecologists must apply ecological principles.
Engineers must understand fundamental
ecological processes.**





Ecological engineering: A field whose time has come

William J. Mitsch^{a,*}, Sven E. Jørgensen^b

^a *Olentangy River Wetland Research Park and School of Natural Resources, The Ohio State University, Columbus, OH 43210, USA*

^b *Environmental Chemistry, Royal Danish School of Pharmacy, Copenhagen, DK, Denmark*

Received 10 May 2002; received in revised form 14 December 2002; accepted 1 May 2003

Abstract

Ecological engineering is defined as “the design of sustainable ecosystems that integrate human society with its natural environment for the benefit of both.” It involves the restoration of ecosystems that have been substantially disturbed by human activities such as environmental pollution or land disturbance; and the development of new sustainable ecosystems that have both human and ecological value. While there was some early discussion of ecological engineering in the 1960s, its development was spawned later by several factors, including loss of confidence in the view that all pollution problems can be solved through technological means and the realization that with technological means, pollutants are just being moved from one form to another. Conventional approaches require massive amounts of resources to solve these problems, and that in turn perpetuates carbon and nitrogen cycle problems, for example. The development of ecological engineering was given strong impetus in the last decade with a textbook, the journal *Ecological Engineering* and two professional ecological engineering societies. Five principles about ecological engineering are: (1) It is based on the self-designing capacity of ecosystems; (2) It can be the acid test of ecological theories; (3) It relies on system approaches; (4) It conserves non-renewable energy sources; and (5) It supports biological conservation. Ecology as a science is not routinely integrated into engineering curricula, even in environmental engineering programs, while shortcoming, ecologists, environmental scientists, and managers miss important training in their profession—problem solving. These two problems could be solved in the integrated field of ecological engineering.

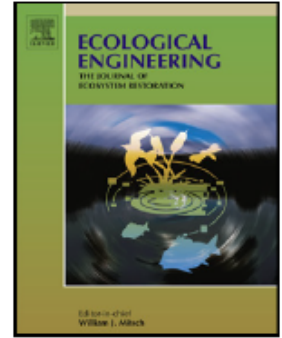


ELSEVIER

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng



When will ecologists learn engineering and engineers learn ecology?



William J. Mitsch (Editor-in-Chief)^{a,b,*}

^a Everglades Wetland Research Park, Juliet C. Sproul Chair for Southwest Florida Habitat Restoration and Management, 110 Kapnick Center, Florida Gulf Coast University, 4940 Bayshore Drive, Naples, FL 34112, USA

^b Professor Emeritus, The Ohio State University, Columbus, OH 43210, USA

ARTICLE INFO

Article history:

Received 5 October 2013

Accepted 6 October 2013

Available online 9 November 2013

Keywords:

Ecological engineering

ABSTRACT


Six large-scale wetland restoration case studies are presented here, three of which relate to ecological engineering of coastlines, and three of which relate to large-scale watershed improvements that in turn lead to improvement of downstream aquatic ecosystems. All of these case studies suggest that there is much more to restoration than returning a system to what it was before, particularly given the drastic changes to the physical and chemical environment.

Circular Economy and Sustainability (2021) 1:333–373
<https://doi.org/10.1007/s43615-021-00067-4>

ORIGINAL PAPER



Education in Ecological Engineering—a Need Whose Time Has Come

Glenn Dale^{1,2}  • Gabriela Dotro³ • Puneet Srivastava⁴ • David Austin⁵ • Stacy Hutchinson⁶ • Peter Head⁷ • Ashantha Goonetilleke⁸ • Alexandros Stefanakis⁹ • Ranka Junge¹⁰ • José A. Fernández L.¹¹ • Vanessa Weyer¹² • Wayne Truter¹² • Devi Bühler¹⁰ • John Bennett² • Hongbo Liu¹³ • Zifu Li¹⁴ • Jianqiang Du^{15,16} • Petra Schneider¹⁷ • Jochen Hack¹⁸ • Andreas Schönborn¹⁰



Available online at www.sciencedirect.com

SCIENCE @ DIRECT®

Ecological Engineering 20 (2003) 331–338

**ECOLOGICAL
ENGINEERING**

www.elsevier.com/locate/ecoleng

Editorial

Ecology, ecological engineering, and the Odum brothers

William J. Mitsch*

*Ecological Engineering, Olentangy River Wetland Research Park, The Ohio State University,
352 W. Dodridge Road, Columbus, OH 43202 USA*

Father of Ecological Engineering

■ Howard T. Odum

- Starting in 1950s (PhD, Yale 1950)
- Studies in systems ecology, ecosystem energy flow and sustainable human society
- Ecological economics and ecological modeling, too!
- Prolific author
- Proposed additional thermodynamic laws based on natural systems
“maximum power principle”



H.T. Odum (1924-2002)

Father of Ecological Engineering

■ Howard T. Odum

- Starting in 1950s (PhD, Yale 1950)
- Studies in systems ecology, ecosystem energy flow and sustainable human society
- Ecological economics and ecological modeling, too!
- Prolific author
- Proposed additional thermodynamic laws based on natural systems
“maximum power principle”

*A promising
young scientist*

H.T. Odum

E.P. Odum

W.J. Mitsch



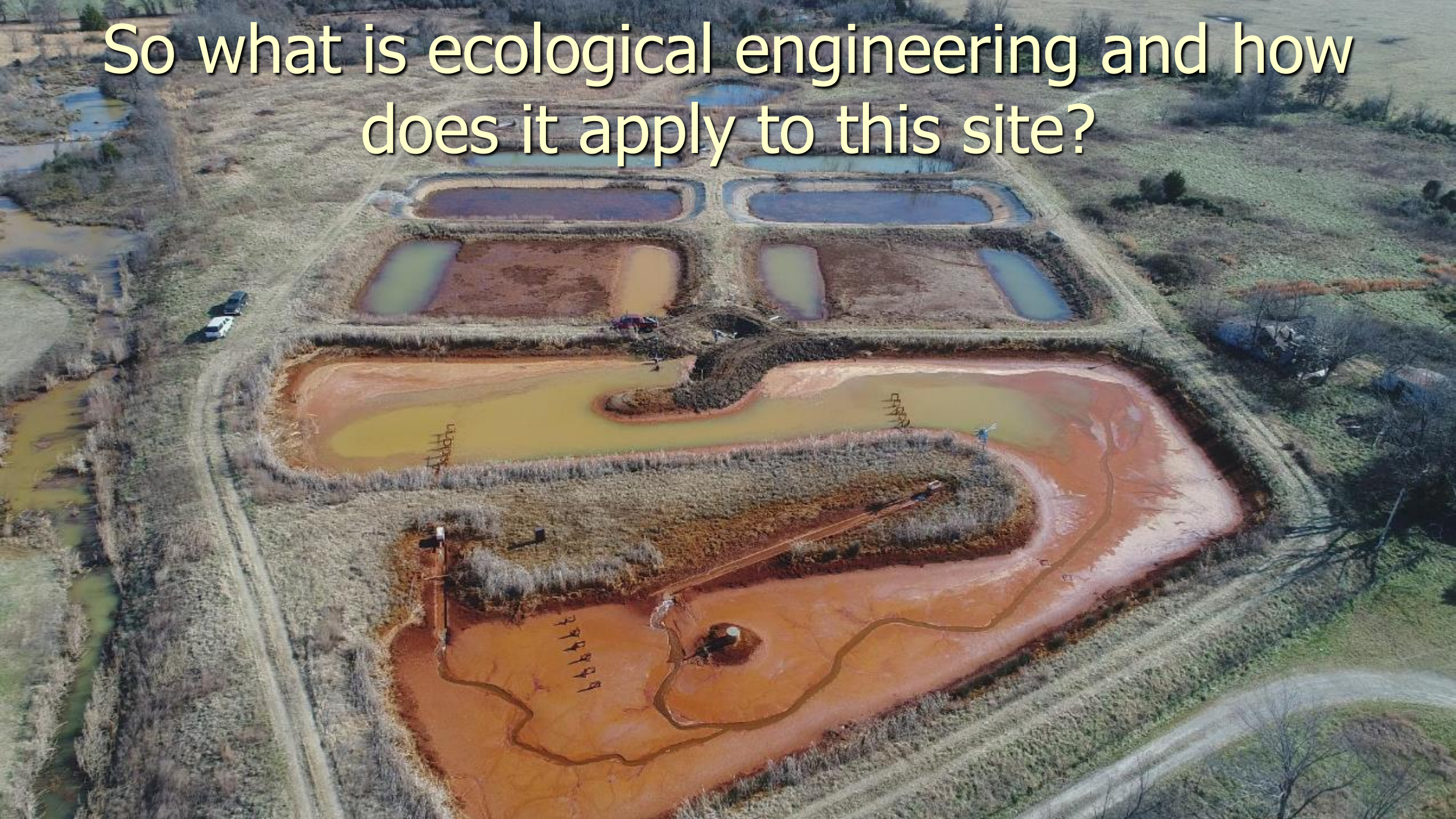
■ William J. Mitsch

- University of Florida (PhD, 1975)
- Wetland scientist
- Ecological engineer
- Prolific author
- Society of Wetland Scientists
Lifetime Achievement Award
- Society for Ecological Restoration
Sperry Award
- Inaugural Odum Award for
Ecological Engineering Excellence
- Stockholm Water Prize Laureate
- Mentor
- Friend



Bill Mitsch 1947-2025

So what is ecological engineering and how does it apply to this site?



Definitions

“those cases in which the energy supplied by man is small relative to the natural sources, but sufficient to produce large effects in the resulting patterns and processes”

Odum, 1962

“the design of human society with its natural environment for the benefit of both”

Mitsch and Jørgensen, 1989

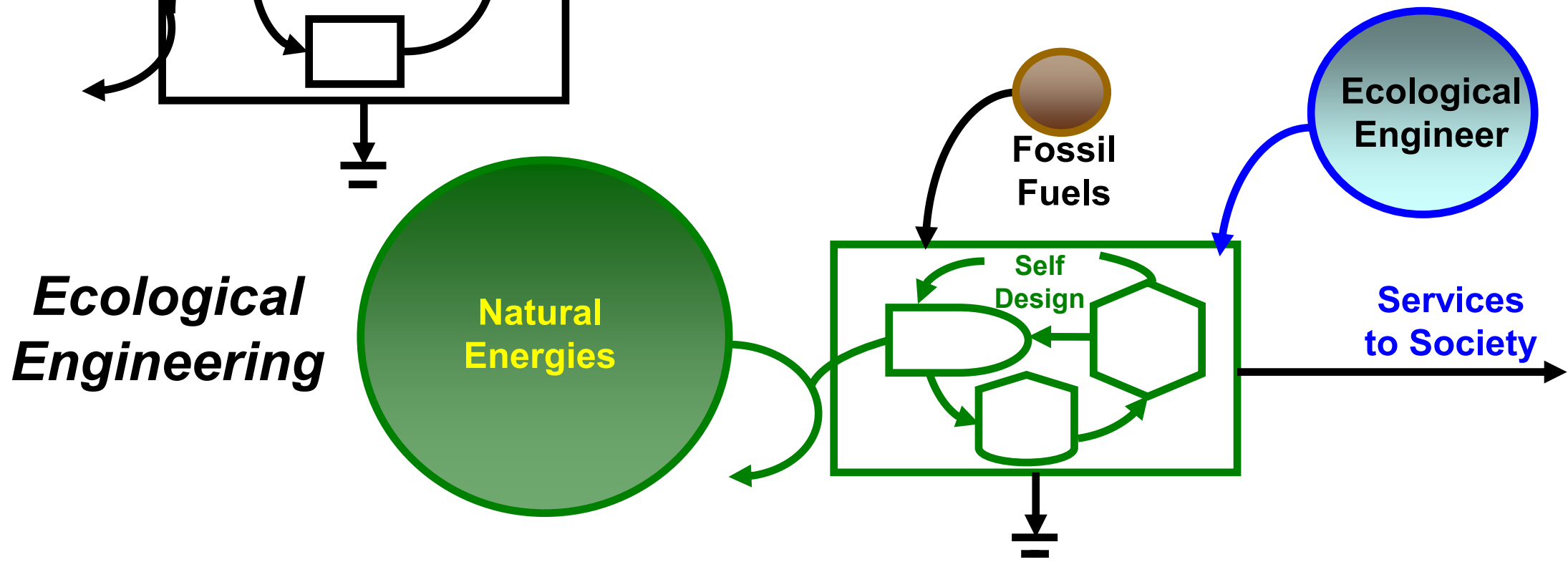
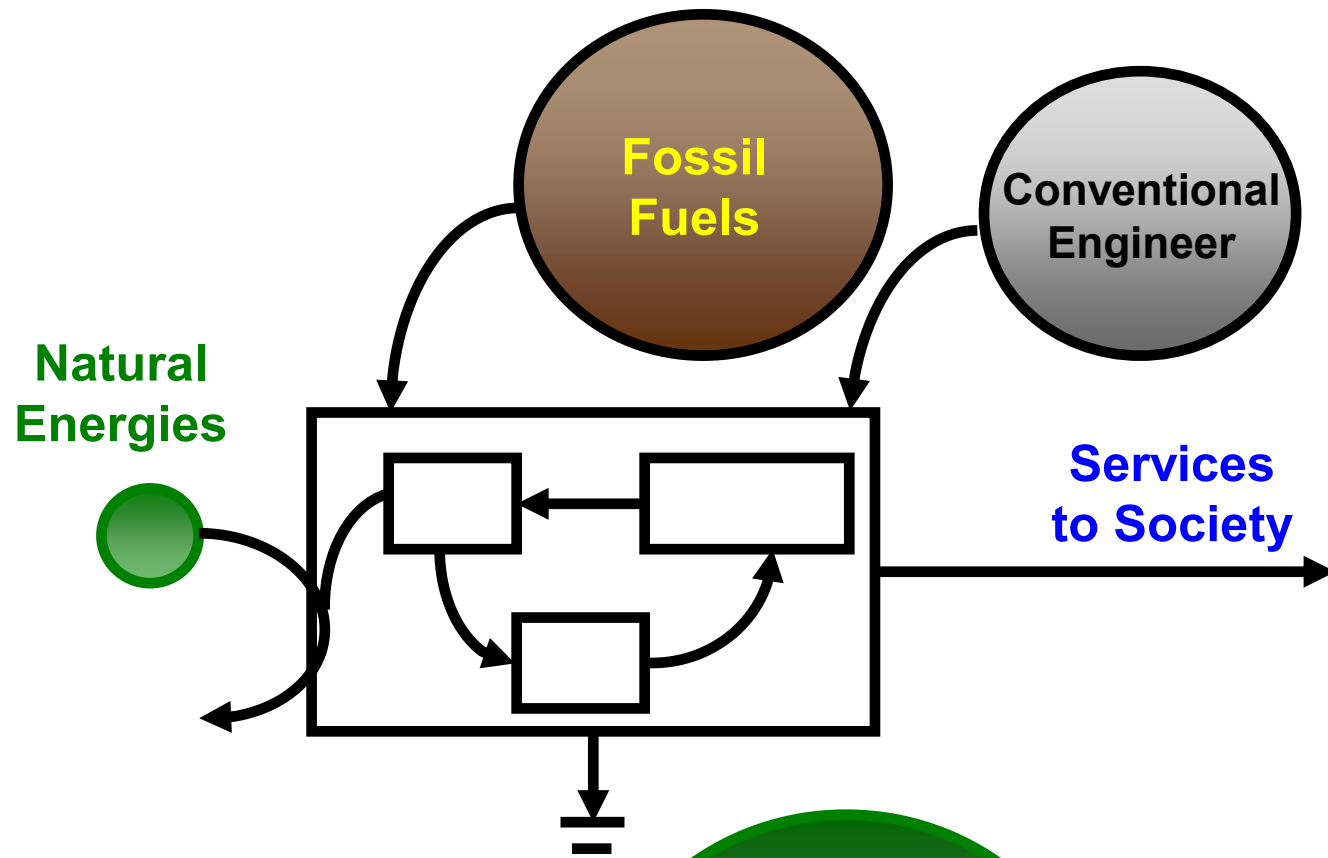
“the building of sustainable and self-designed ecosystems”

Mitsch, 1993

Today's Definition

"The design of sustainable ecosystems that integrate human society with its natural environment for the benefit of both."

Mitsch and Jørgenson, 2004



Ecological Engineering Goals

- Restoration of disturbed or polluted ecosystems
- Creation of new sustainable ecosystems with human and ecological value
- Prescriptive approach
 - Not only describes environmental effects but...
 - *Prescribes solutions*

Ecological Engineering as an Ethical Construct

- The identification of the life support value of ecosystems to ultimately lead to conservation
- *“Ecological engineering ethics, at its most fundamental, concerns the moral principles guiding the design, implementation, and management of engineered ecosystems. It asks us to consider the impacts of our interventions on both the natural world and human society.”*

(The Sustainability Directory 2025)



Descriptive vs. Prescriptive Approaches

Descriptive

- Ecotoxicology, landscape ecology, etc.
- Describe human effects
- Insufficient to manage problems
- Insufficient to find solutions

Prescriptive

- Ecological engineering
- Restoring damaged and building new ecosystems
- Ecologically sound harvesting
- Combining basic and applied science

The Building Blocks

1. Self-design
 - Ecosystems self-organize to maximize efficiency
2. Biological Components
 - Not purely physical systems
3. Sustainability
 - Indefinite ecosystem maintenance with modest human influence



1. Self-Design

- Outcome of the second law
 - Decreased entropy, increased information, resistance stability, energy efficiency, nutrient utilization
- *Self-design is the application of self-organization in the design of ecosystems*
- *Self-organization is the property of systems to reorganize themselves given an environment that is inherently unstable and nonhomogenous*

1. Self-Design

- Ecosystems will self-organize to maximize efficiency
- Changes cause system shifts, species substitutions, food web reorganization, etc.
- New system emerges well-suited for conditions
- Self-design in ecologically engineered systems
 - Choices provided by humans
 - Prospective species
 - Physical conditions
 - Step back and “**Let Mother Nature do her thing**”

2. Biological Components

- Implicitly includes biologically-mediated processes
- Incorporates understanding of importance of biodiversity
- Includes human society as part of systems



2. Biological Components

- Resourcism vs. preservationism
- Output rule
 - Emission rates within assimilative capacity
- Input rule
 - Harvest rates within regenerative capacity



3. Sustainability

- Indefinite ecosystem maintenance with modest human influence
- Based on solar energy
- Loss of maintenance in original design does not equal failure
 - Probably ecological engineer made mistake!



Basic concepts

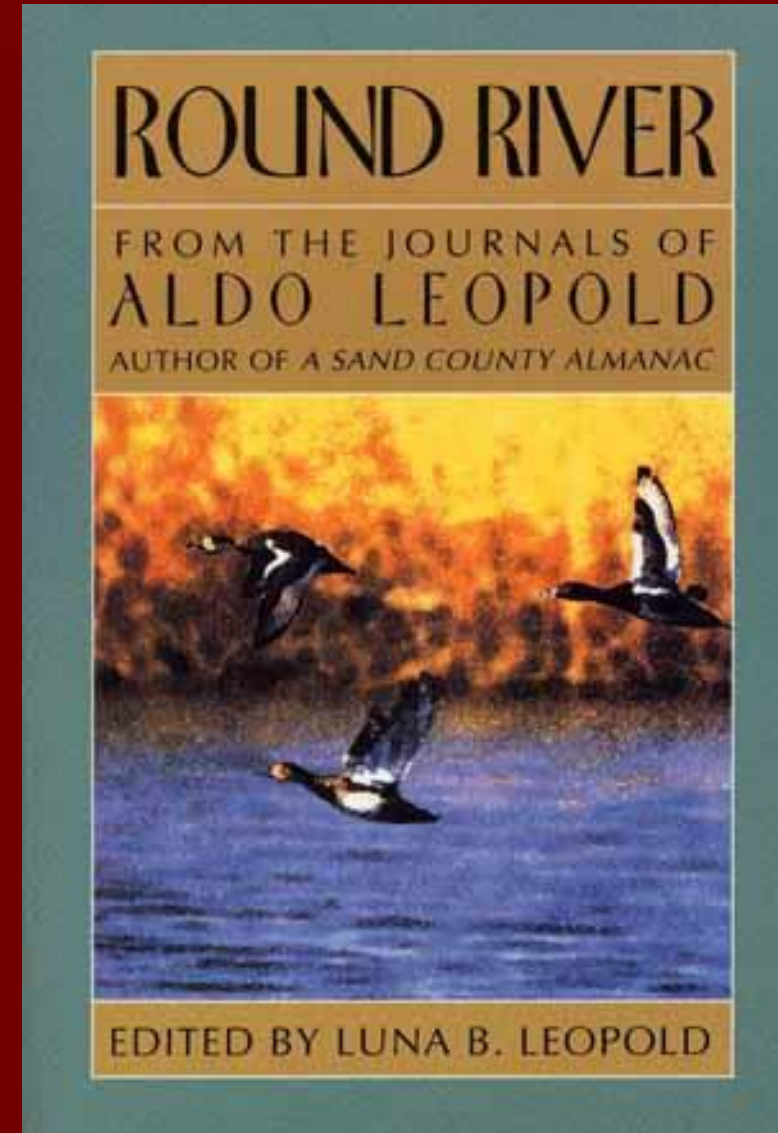
1. Self-designing capacity of ecosystems
2. Incorporation of biological processes
3. Conserves nonrenewable energies
4. Supports ecosystem conservation
5. Acid test of ecological theories
6. Recognizes systems approach



Olentangy River Wetland Research Park,
Columbus, OH

4. Promotes Conservation

- Sustainability leads to conservation and vice versa
- Mutually beneficial adaptabilities
- *"The first rule of an intelligent tinkerer is to keep all of the parts!"*



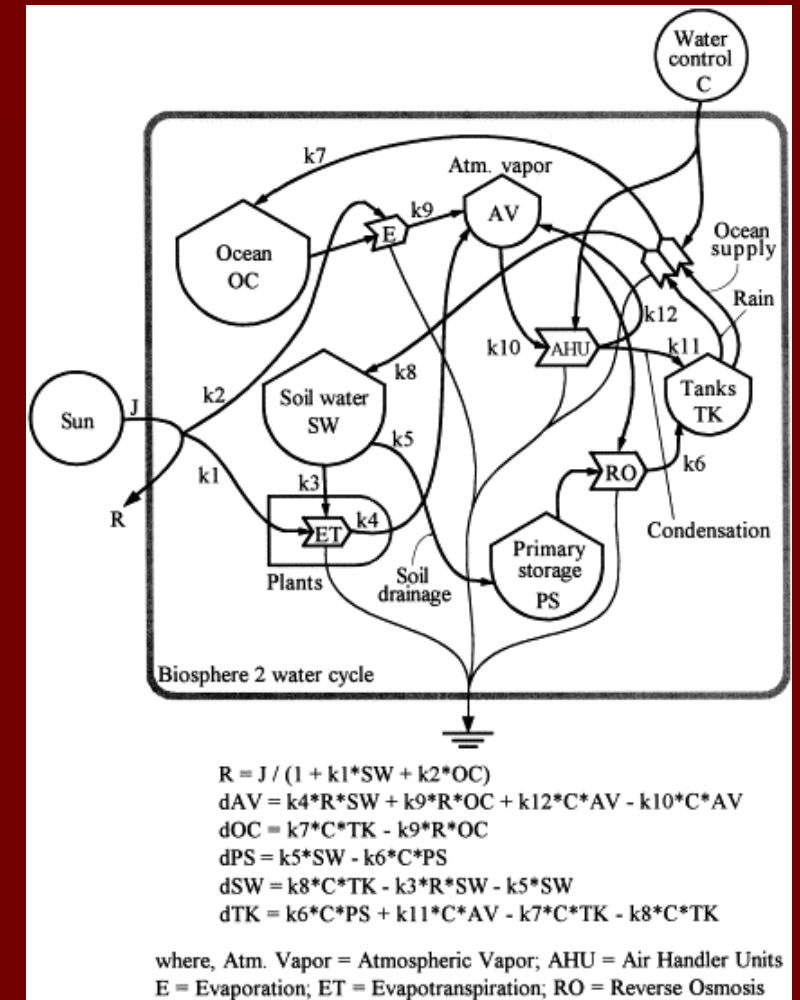
5. Founded in Ecological Theory

- Validation of many ecological theories
- Restoration of disturbed ecosystems as the "*acid test of our understanding*"
- Reassembling a car analogy



6. Very Much a Systems Approach

- Self-organization “*is meaningless at the level of the parts*”
- Cannot be supported solely by reductive, analytic experimental testing approaches
- Synthesis is key!



Energy systems diagram and equations of the Biosphere2 water cycle (Kang 1999)

Municipal Wastewater Treatment

Traditional Engineering



Wastewater treatment facility

Ecological Engineering



Treatment wetlands

River Management

Traditional Engineering



Channelized navigation canal

Ecological Engineering



Re-meandered stream

Stream Management

Traditional Engineering



“Improved” channel

Ecological Engineering



AFGM “Bioengineered” bank

Land Reclamation

Traditional Engineering



Soil washing operation

Ecological Engineering



Phytoremediation

Industrial Water Treatment

Traditional Engineering



Mine water treatment plant

Ecological Engineering



Mine water treatment plants!

Kidneys, Supermarkets, Thermostats and Wetlands



Wetland Ecosystems

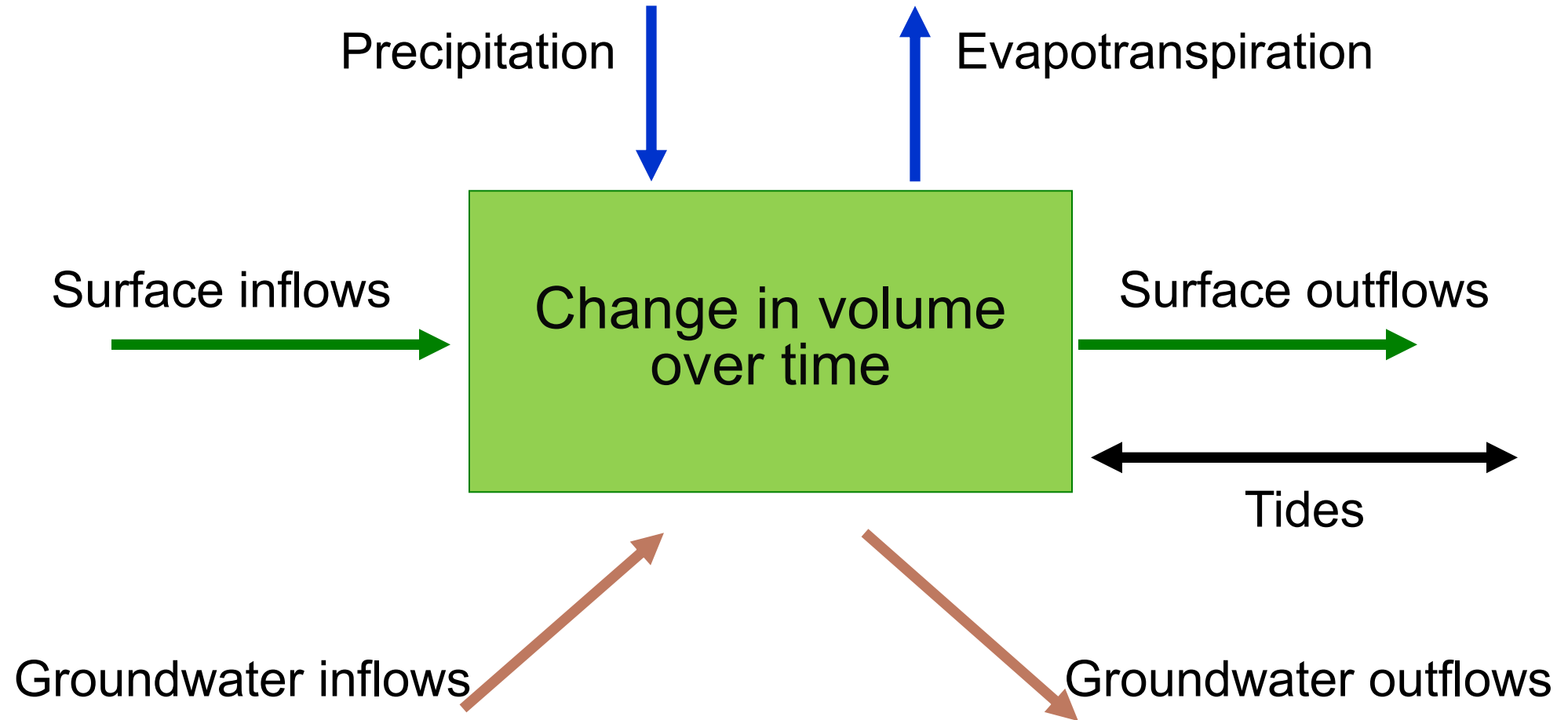
Distinguishing Features

- Hydrologic conditions
 - Water at the surface or within the root zone
- Hydric soils
 - Unique soil conditions under anoxic conditions
- Hydrophytic Vegetation
 - Adaptations to water-logged, anoxic conditions (and absence of flood-intolerant vegetation)

Design Features

- Hydrology
 - Flood duration, frequency, depth, hydroperiod
- Biogeochemistry
 - Oxidation-reduction interface, organic accumulation, elemental cycling
- Ecological Structure and Function
 - Richness, abundance, diversity, productivity

Wetland Hydrologic Budget



$$\frac{\Delta V}{\Delta t} = S_i + P + G_i - S_o - ET - G_o \pm T$$

Wetland biota are not passive to hydrology!

- Vegetation
- Beavers
- Muskrats
- Alligators
- Microbes
- Humans



Inflows

Intrasystem cycling

Outflows

Wetlands Biogeochemistry 101

Atmospheric

Translocation

Atmospheric

Living Biomass

Surface

Surface

Subsurface

Subsurface

Root Zone

Nutrients

Uptake

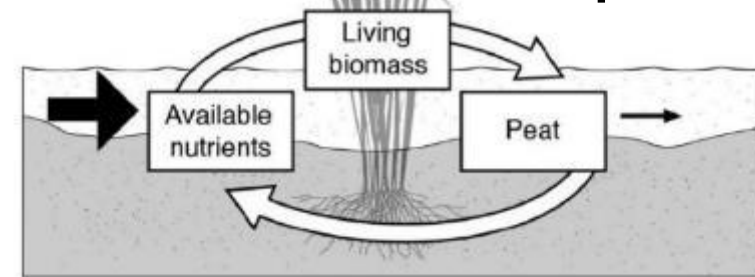
Peat

Mineralization

Loss to deep sediments

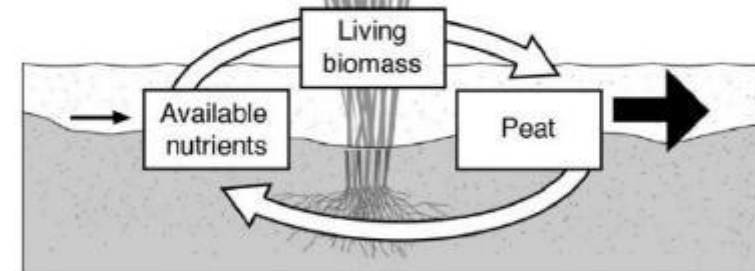
Sink

Total Phosphorus



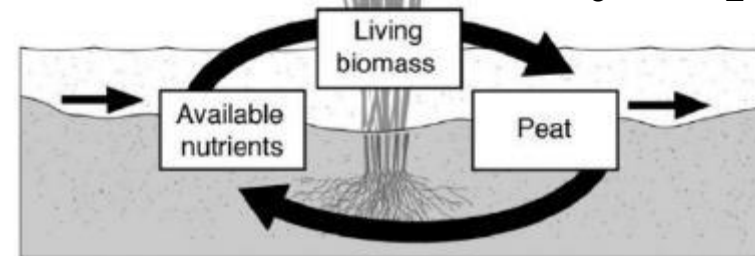
Source

Organic Carbon



Transformer

Nitrogen ($\text{NO}_3^- \rightarrow \text{N}_2$)



Changes at the Redox Interface

- Measure of electron pressure, used to quantify degree of electrochemical reduction in wetland soils



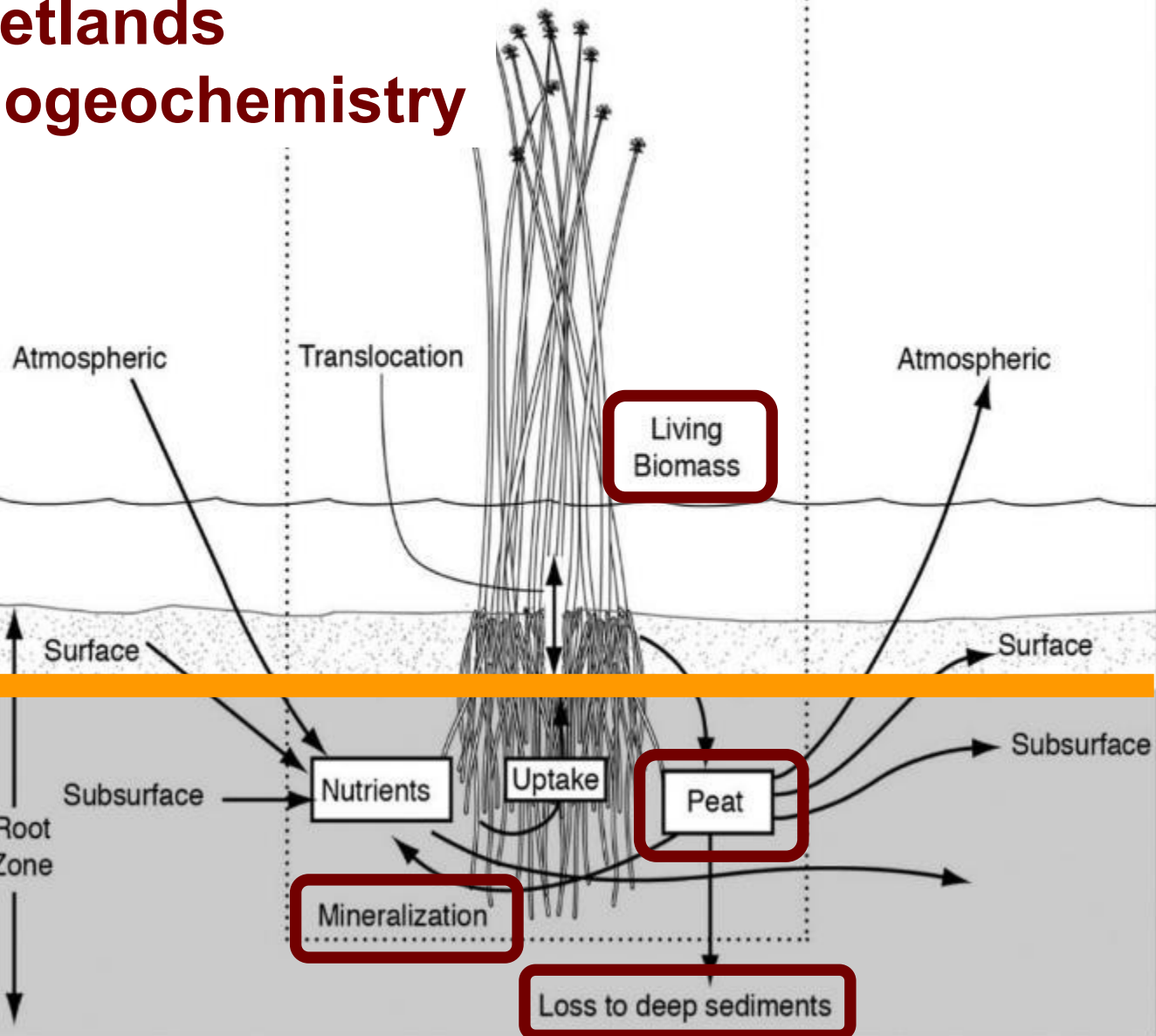
	Oxidized form	Reduced form	≈Redox (mV)
Nitrogen	NO_3^-	N_2O , N_2 , NH_3^-	250
Manganese	Mn^{4+}	Mn^{2+}	225
Iron	Fe^{3+}	Fe^{2+}	+100 to -100
Sulfur	SO_4^{2-}	S^{2-}	-100 to -200
Carbon	CO_2	CH_4	Below -200

Inflows

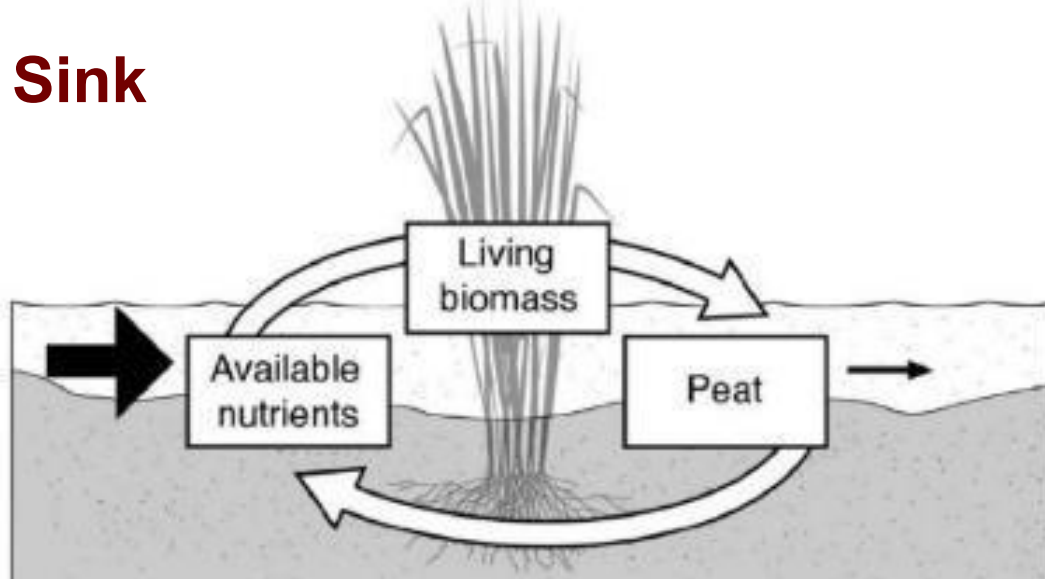
Intrasystem cycling

Outflows

Wetlands Biogeochemistry



Sink



Kidneys of the Landscape

Wetland Biotic Adaptations

- Stressful place to live!
 - Anoxia
 - Temperature/water stress
 - Periodic drying/flooding
 - Salinity
- Biological adaptations
 - Cellular
 - Structural
 - Physiological
 - Behavioral



Diverse and Productive Biota Nature's Supermarket





Wetlands store massive amounts of carbon

- If temperatures rise 5°C
- ...change from net sink for carbon to...
- Net source of ≈ 1.25 Pg/yr of CO₂

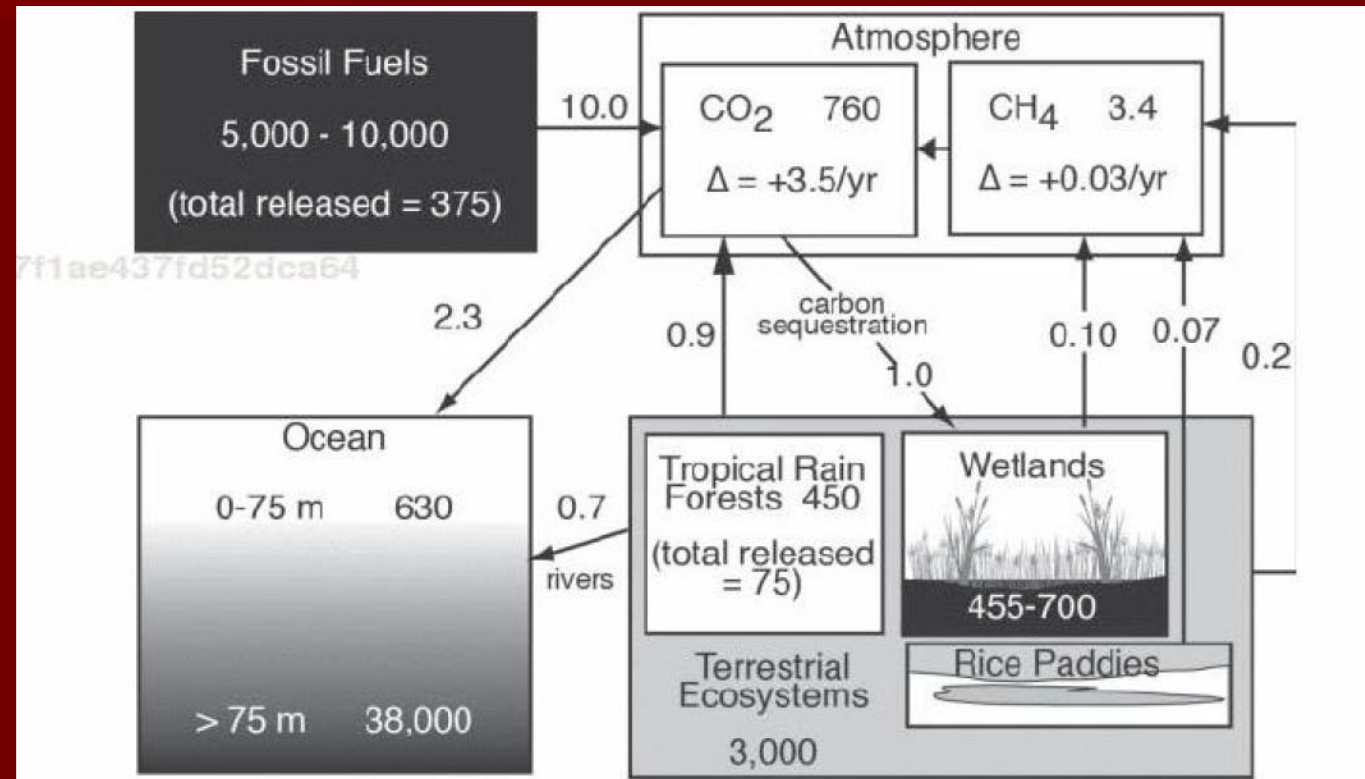


Figure 17.4 Global carbon budget with estimated role of wetlands in the carbon cycle. Fluxes are in Pg/yr; storages are in Pg. Pg = 10¹⁵ g. (CH₄ emissions from wetlands and rice paddies from Bloom et al., 2010; terrestrial ecosystem and fossil fuel inputs to CO₂ from IPCC, 2013; carbon sequestration by wetlands from Mitsch et al., 2013)

Wetlands Moderate Climate Global Thermostat



SCIENCE TRANSFORMED HIM INTO A MONSTER.
LOVE CHANGED HIM EVEN MORE!

*My best,
Adventure
Daredevil*

*All the Best
from Alec Holmquist
Ray Wise*



SWAMP THING

TM & © DC Comics, Inc. 1981

THE COMIC BOOK LEGEND LIVES!

CREATURE FROM THE BLACK LAGOON



Starring

RICHARD CARLSON · JULIE ADAMS

— RICHARD DENNING · ANTONIO MORENO · NESTOR PAIVA · WHIT BISSELL

Created Wetlands

- Conversion of persistent upland or shallow-water area into wetland by human activity
- Creating a wetland where one never existed
- Usually requires substantial hydrologic alteration

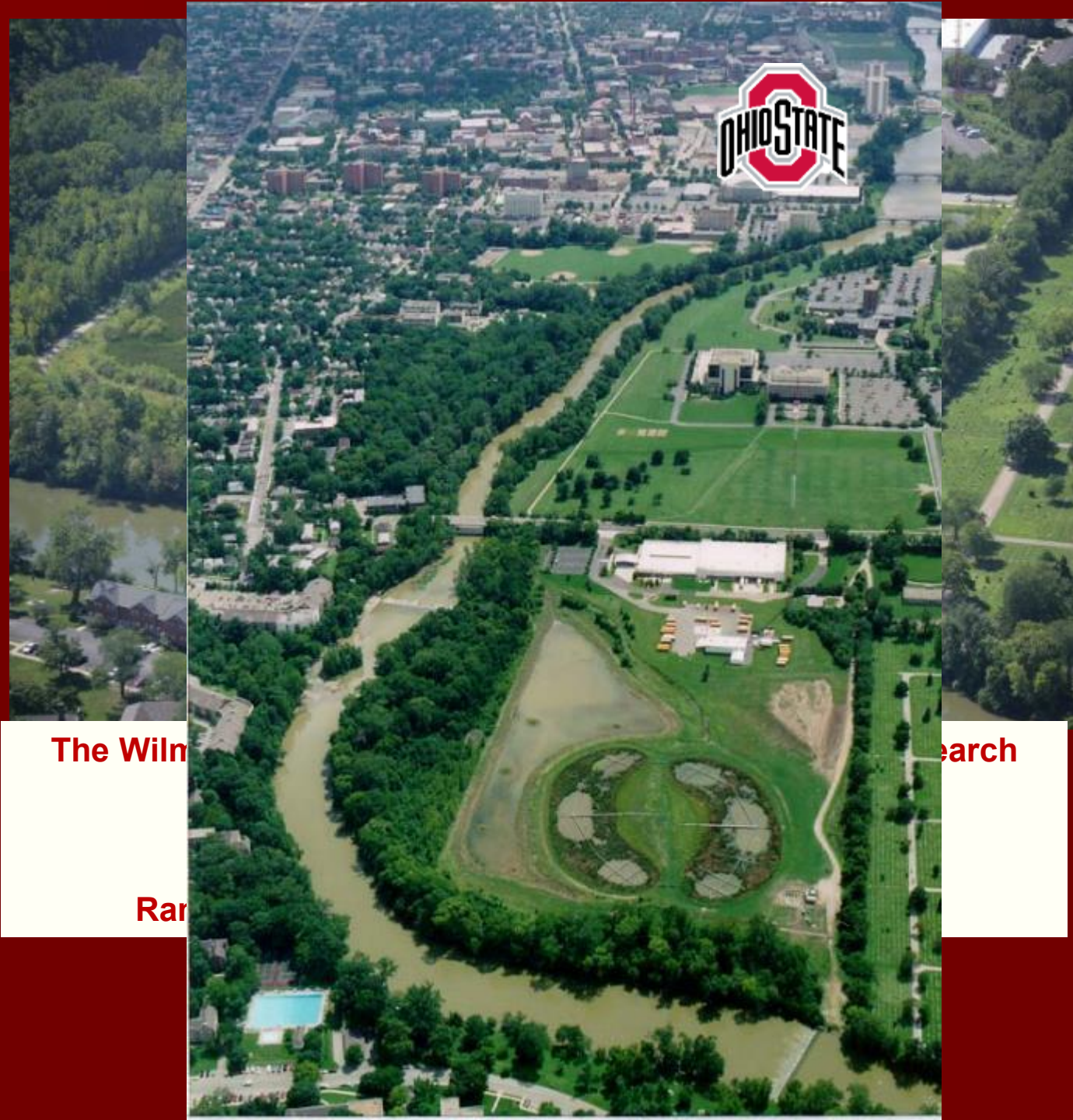


**The Wilma H. Schiermeier
Olentangy River Wetland Research Park
The Ohio State University, Columbus, OH**

**Created 1994
Ramsar Wetlands of International Importance 2008**

Created Wetlands

- Conversion of persistent upland or shallow-water area into wetland by human activity
- Creating a wetland where one never existed
- Usually requires substantial hydrologic alteration



The Wiln

Rar

earch

Restored Wetlands

- Return from disturbed or altered condition to previously existing wetland condition
- Restoration of hydrology may be enough to restore wetland conditions



**Hackberry Flat Wildlife Management Area
Tillman County, OK**

Restored Wetlands

- Return from disturbed or altered condition to previously existing wetland condition



- “President Theodore Roosevelt was intrigued by the area, and even went for a hunt on Hackberry Flat. However, it was not the wildlife that drew rugged homesteaders, but rather the valuable commercial potential of the soil. In the early 1900s, a massive ditch was constructed – some four miles long, 20 feet deep and 40 feet wide – by locals using hand shovels, mule teams and later a steam shovel. The next two generations of area residents maintained the area as farmland instead of the wetland it had been for so many years prior. They had some success in the fertile soil, but the area remained flood-prone so farming was difficult.”

Treatment Wetlands

- Wetlands designed and built explicitly for water quality improvement
- Exploit biogeochemical diversity and sink capabilities
- Partnership between humans (our wastes) and ecosystems (wetlands)
- Application of ecological engineering



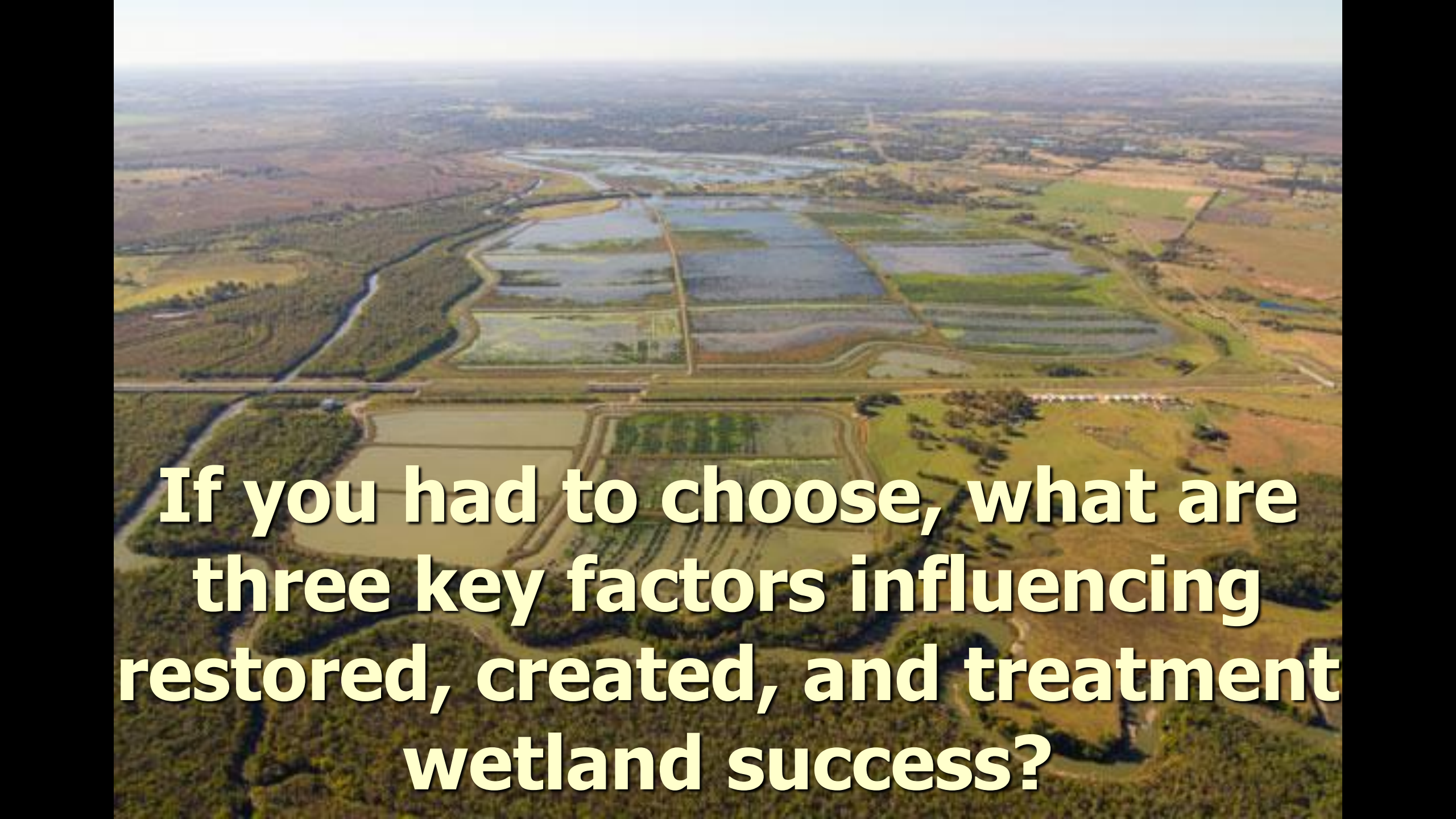
Two Guiding Principles

1. Learn and understand wetland science
 - Hydrology, soils, biogeochemistry, adaptations, ecosystem development
2. Broaden horizons and resist temptation to over-engineer, over-botanize, over-zoologize
 - *Mother Nature is in control!*
 - Channel natural energies, avoid introduction of species that cannot be supported

Define Goals

- Maximize ecosystem longevity
- Minimize costs
- Choose primary (and secondary, if needed) goals
 - Habitat replacement
 - Wildlife enhancement
 - Fisheries enhancement
 - Flood control
 - Storm surge protection
 - Water quality improvement



An aerial photograph showing a large-scale wetland restoration project. The landscape is dominated by numerous rectangular and irregularly shaped ponds and channels, some filled with water and others with mud or vegetation. The surrounding area is a mix of green fields, brown soil, and patches of trees. The sky is clear and blue. The text is overlaid on the lower half of the image.

If you had to choose, what are three key factors influencing restored, created, and treatment wetland success?

Hydrology, hydrology, hydrology!

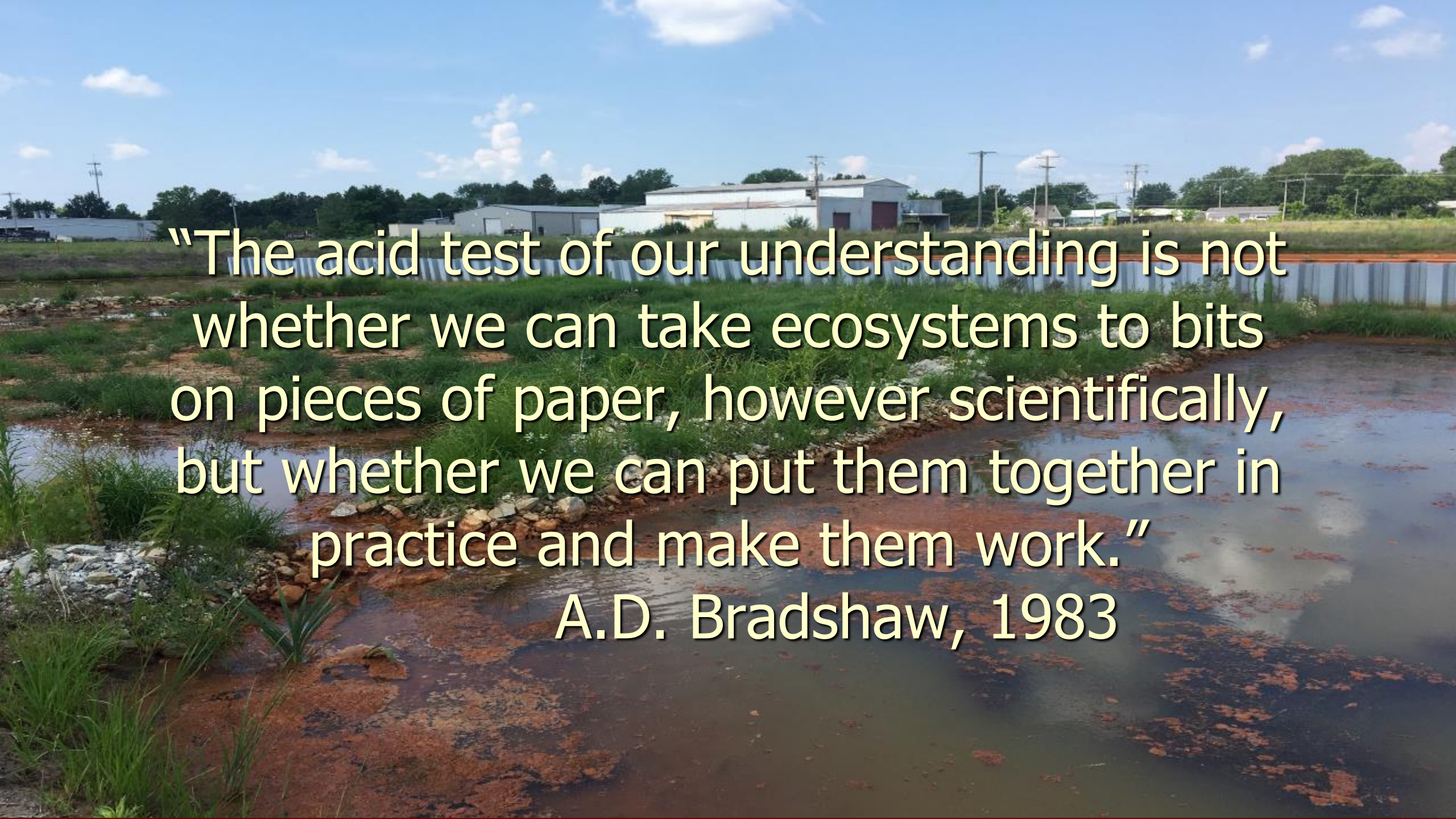
- Appropriate hydrology is key!
- Groundwater interaction may be important
- Surface flooding may be seasonally important
- Big problems:
 - Many ecologists don't understand hydrology
 - Most engineers tend to control hydrology



Summary Principles

1. Design for minimum maintenance and reliance on self-design
2. Design using natural energies as pulsing subsidies
3. Design with hydrology, ecology, ecological landscape and climate
4. Design to fulfill multiple objectives, but identify primary goal
5. Give the system time
6. Design for function not form
7. Do not over-engineer!



A photograph of a wetland or stormwater treatment pond. The foreground shows a shallow, reddish-brown water body with some green vegetation and rocks. In the background, there is a large, white, industrial-style building with a red door, surrounded by trees and utility poles under a blue sky with scattered clouds.

“The acid test of our understanding is not whether we can take ecosystems to bits on pieces of paper, however scientifically, but whether we can put them together in practice and make them work.”

A.D. Bradshaw, 1983