IWMI International Water Management Institute

CGIAR

Water Accounting +

WA + Fundamental Concepts - II (Beneficial vrs non-beneficial, Budyko, Incremental, Blue and Green ET)

October 27, 2022 - Session III

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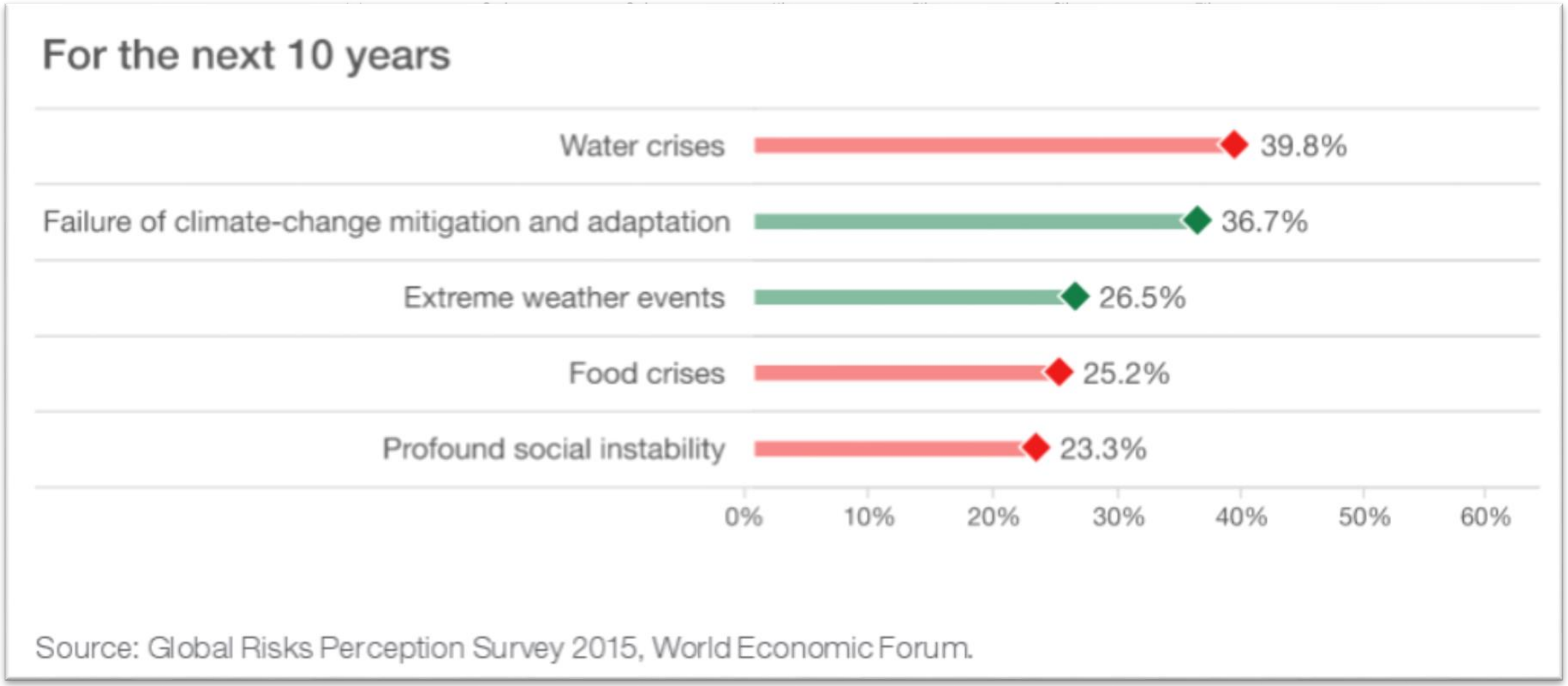
DAY 2	Rapid WA+ (WAPORWA), Analysis, Synthesis and interpretation	
Session I	WA + Fundamental Concepts - II (Beneficial vrs non-beneficial, Budyko, Incremental, Blue and Green ET) Exercise : Separation of ET into Blue, green	Prabhath/Mansoor
	Rapid WA using WAPORWA	
	Hands on: WAPORWA - WA+ Data sources, download and preprocessing	
Break		
Session II	Hands on: Remote sensing data validation (Rainfall, ET)	Komlavi
Lunch		
Session III	Hands on: WAPORWA -Soil Moisture Balance modeling, generating resource base sheet	Prabhath/Mansoor
Break		
Session IV	Group discussion, Wrap-up Post training assessment Closing remarks	Mansoor Youssef

Why our work is so important?

Global Risks 2021 Report

Published by the World Economic Forum, shows water as one of the top risks in terms of impact, consistently over last several years.

Top Global Risks by Impact



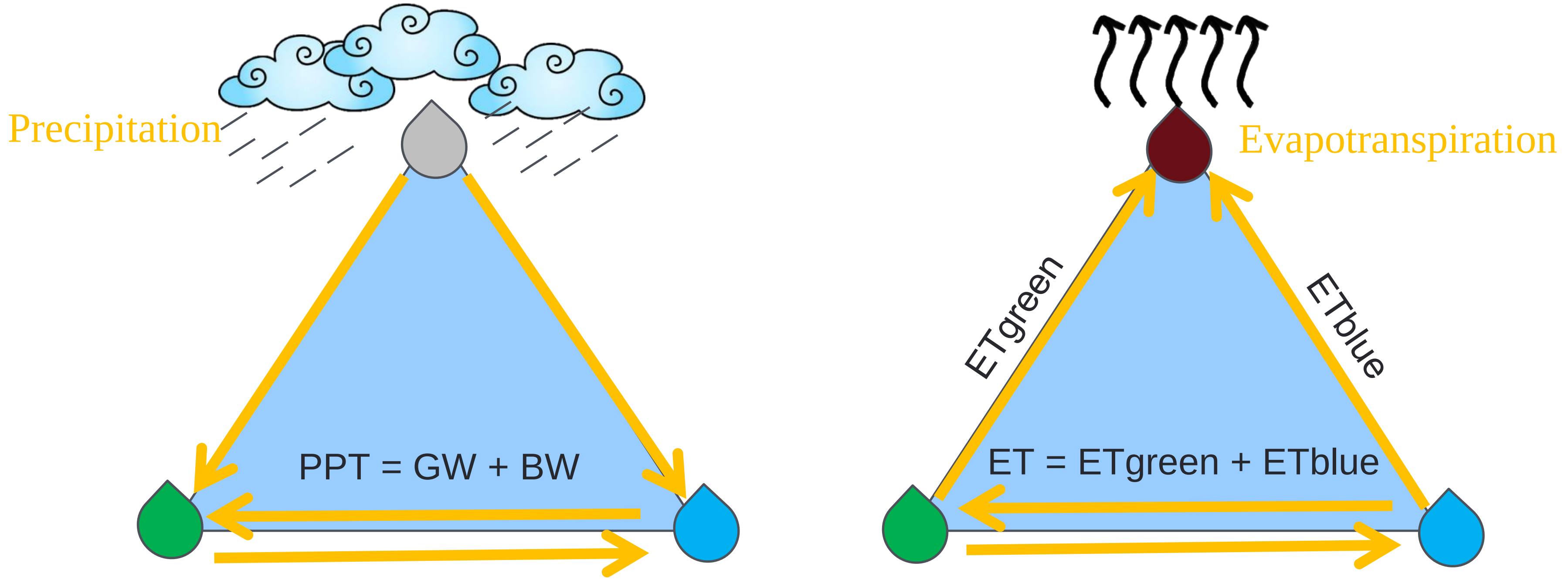
Source: World Economic Forum Global Risks Perception Survey 2020

What comes to your mind when you think of water in the natural landscapes?

- Classical hydrological research is typically based on rainfall and streamflow measurements;
- Quantification of ET processes is not give much attention.
- WA+ focuses on ET and its components
- Blue ET and Green ET

Blue ET and Green ET

- Terms Blue and Green Water were first used by **FAO, 1995**
- Popularized after **Falkenmark and Rockstorm (2006)**



Green Water
(moisture in unsaturated soil layer)

Blue Water
(water in the rivers, streams, surface water bodies and groundwater)

Blue ET and Green ET

- Green ET is mostly from the soil moisture replenished by the rainfall. Hence on a annual time scales,

$$ET_{green} \leq Rain$$

- Blue ET is from sources comes from water that is stored in rivers, lakes, aquifers etc., (where storage supply ≠ 0)

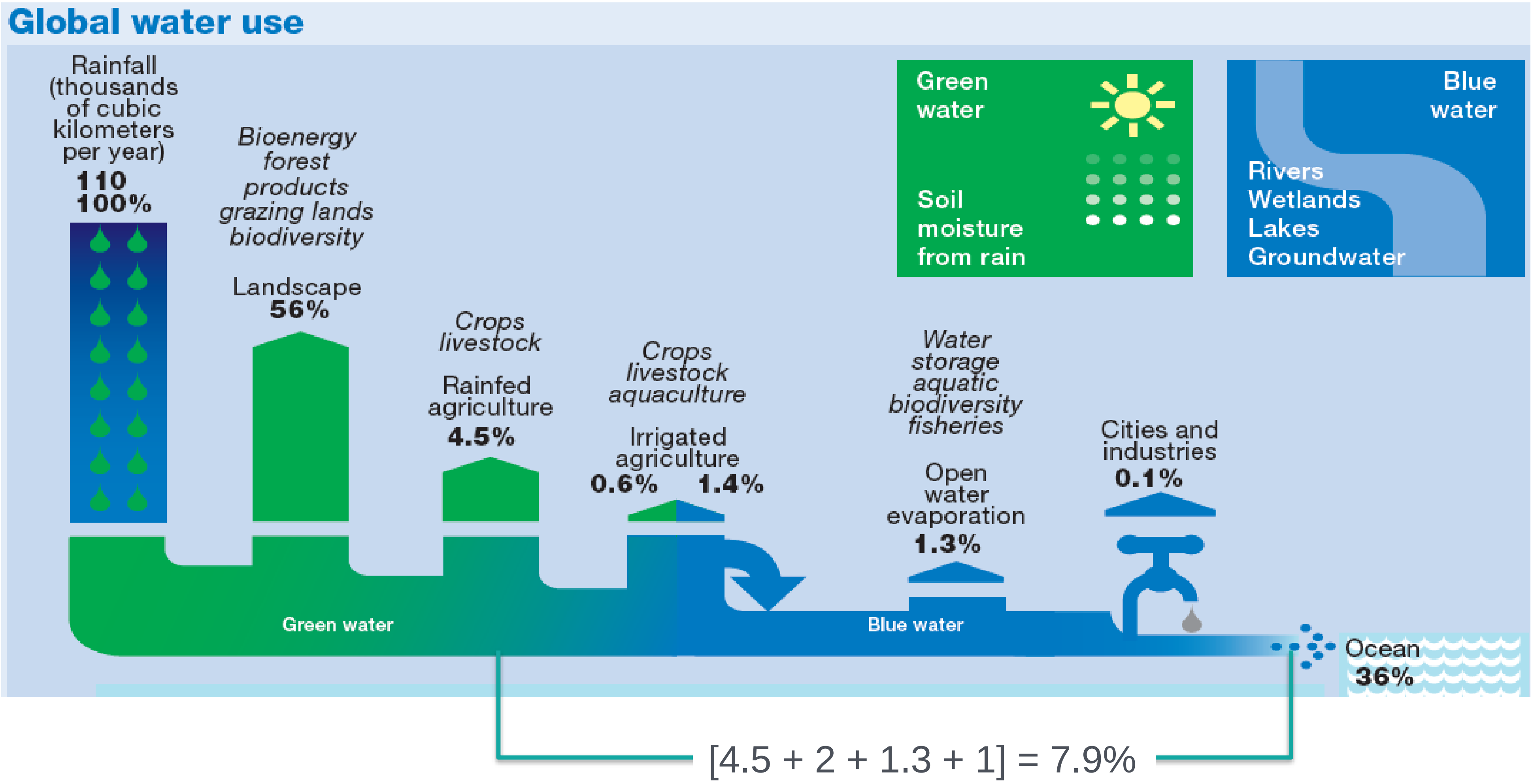
$$ET_{blue} > Rain$$

In arid regions, where rainfall is too small

$$ET_{blue} <= Rain$$

In semi-humid to humid regions, where rainfall is moderate to large

Green and blue water flows



Green and blue water ET

- Methods to partition ET by water supply are cumbersome and have been applied mostly on Croplands globally.
- Answers ***how much of water is being used for irrigation and where is it coming from?***
- Important for better management of water resources

In the arid regions

ET = Irrigation (BW)

Rainfed Croplands

ET = Rain (GW)

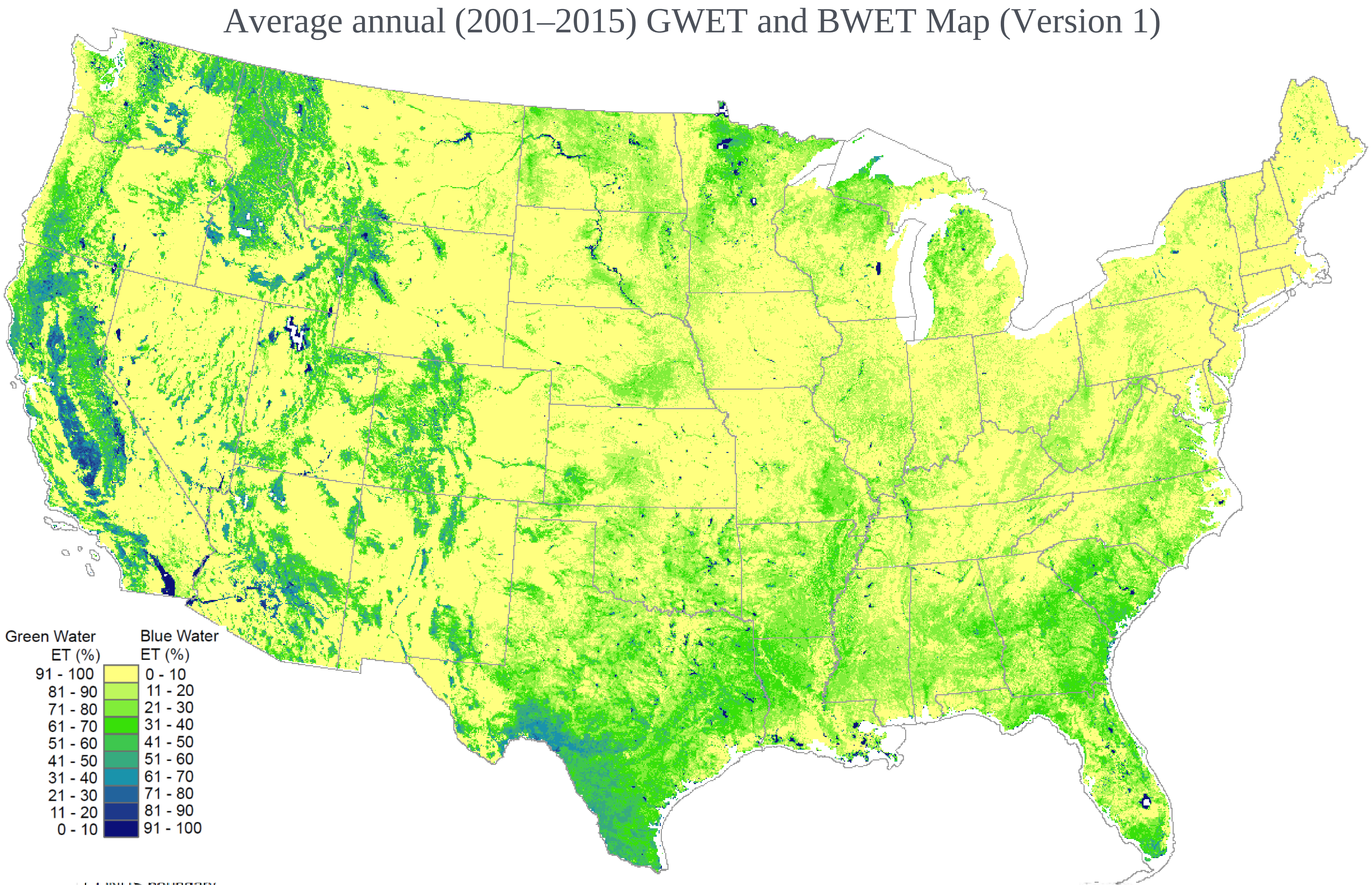
Natural landscapes (grasslands)

ET = Rain (GW)

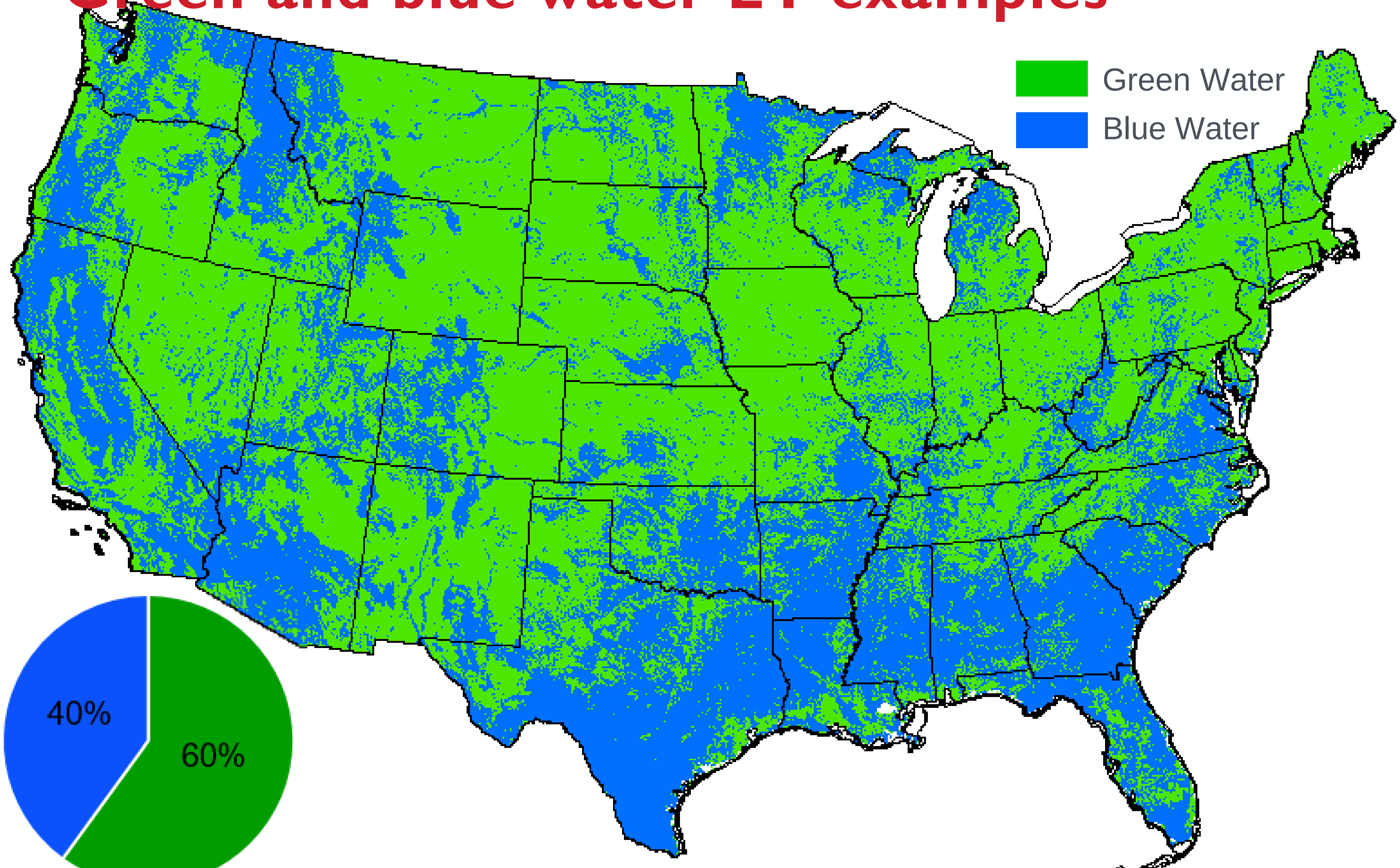
Supplemental Irrigation,

ET = Rain + Irrig
ET = GW + BW

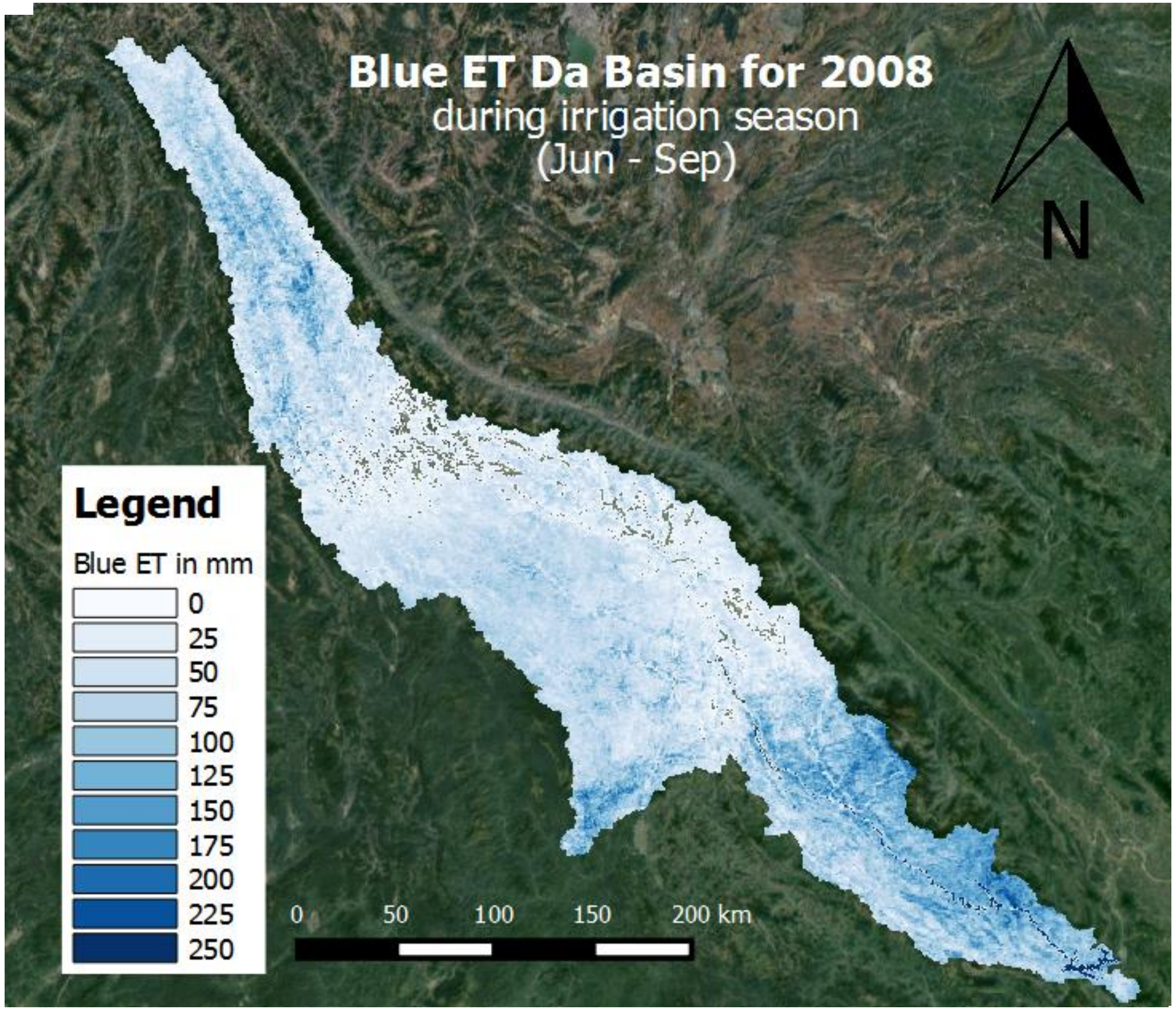
Green and blue water ET examples



Green and blue water ET examples



Green and blue water ET examples



How can we quantify green and blue ET?

- Budyko Hypothesis

Mikhail Ivanovich Budyko
Russian climatologist
1920 –2001

Budyko Curve describes the theoretical energy and water limits on the catchment water balance (P-ET=Q).

Budyko Curve provides a "business as usual" reference condition for the water balance.

If we assume it depicts the expected partitioning of P into ET and Q,

then we can begin to account for the reasons why sites depart from the baseline.

Can the Budyko Curve be used to identify catchments undergoing shifts in water yields or at risk of undergoing these shifts?

Budyko Hypothesis

- Many decades ago, Mikhail Budyko studied observations of over a thousand catchments to find that climate aridity controls most of their *long-term* partitioning of precipitation into streamflow and evapotranspiration (Budyko, 1950). He formalized this pattern into Budyko curve:

$$\frac{E}{P} = \left[\frac{E_p}{P}\tanh\left(\frac{P}{E_p}\right)\left(1 - \exp\left(-\frac{Ep}{P}\right)\right)\right]^{1/2}$$

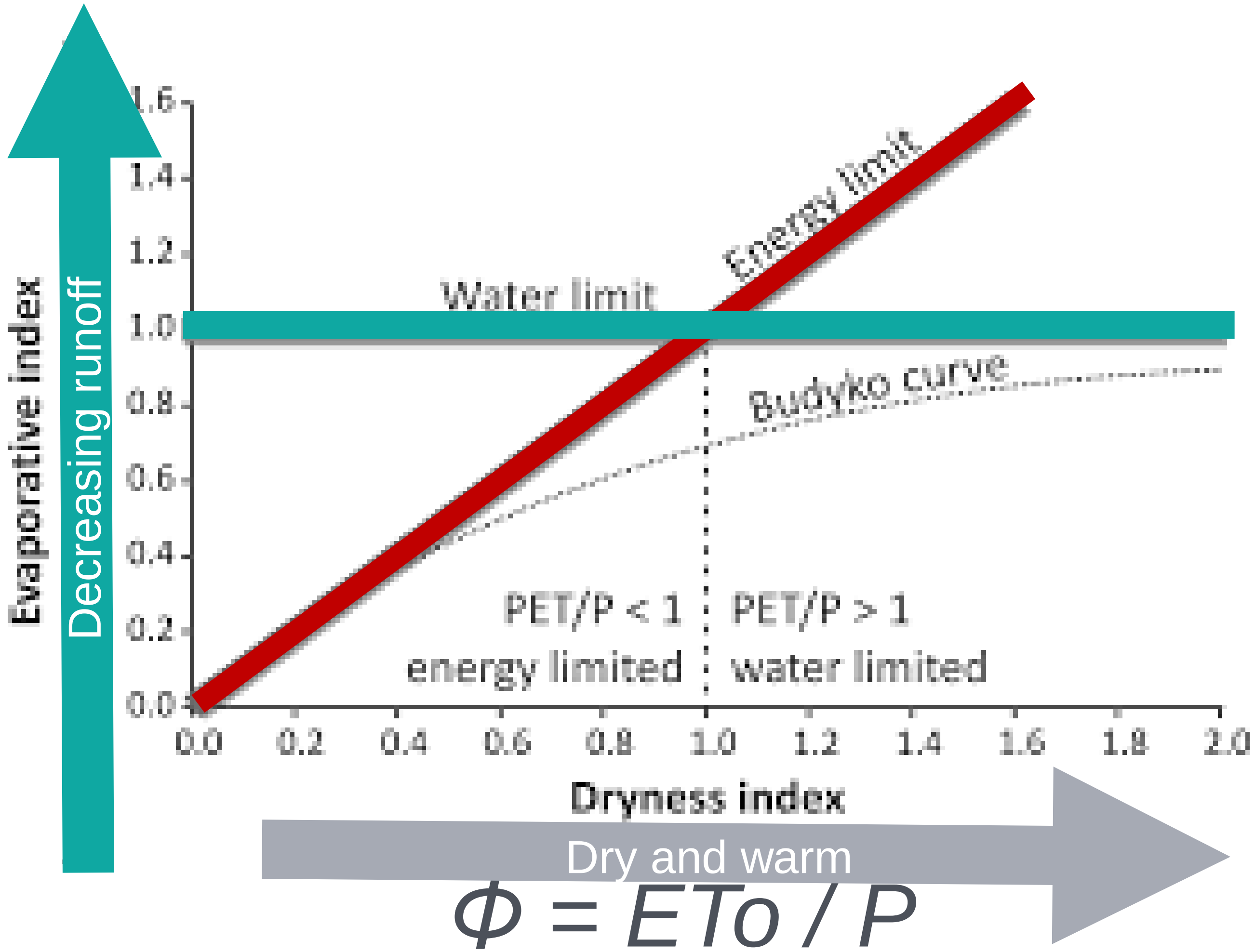
The mean annual water balance is described by the evapotranspiration ratio (AET/P) and the climate aridity index (ETo/P).

Budyko Hypothesis

- ET $\rightarrow$ ETo as P $\uparrow$ $\propto$ (wet condition)
  - ET is energy limited by ET0
- ET $\rightarrow$ P as ETo $\uparrow$ $\propto$ (dry condition)
  - ET is water limited by P

Budyko Hypothesis

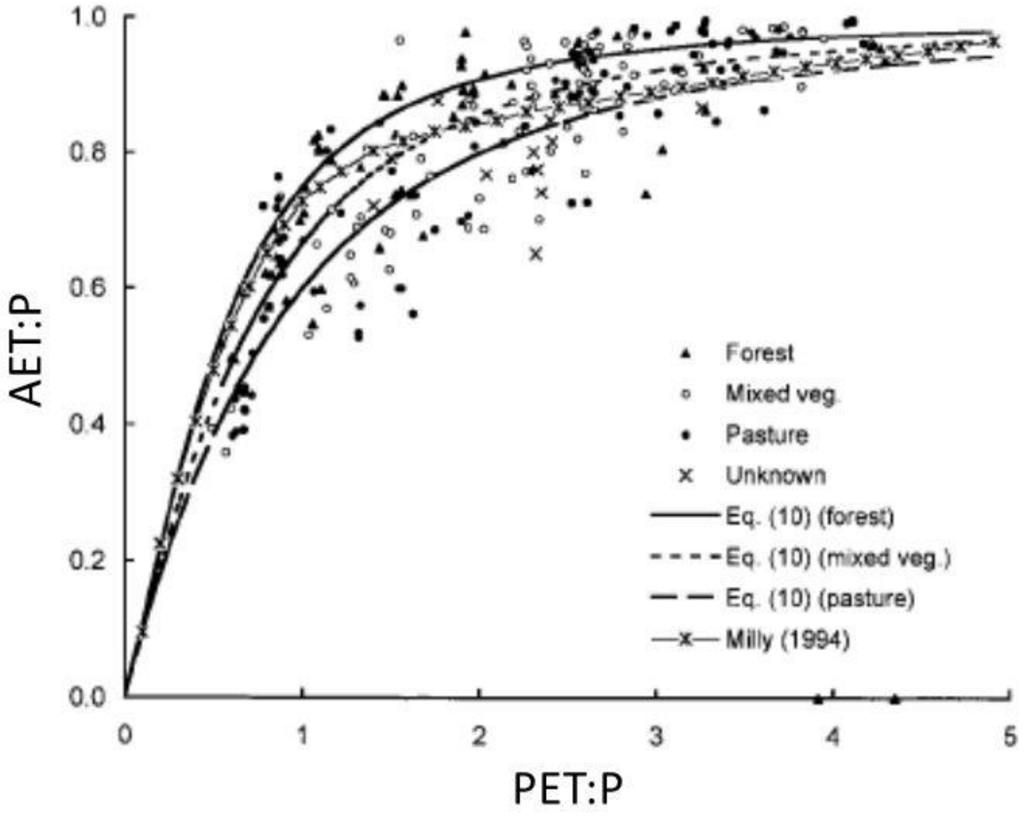
AET/P



$$\Phi = ETo / P$$

Budyko Hypothesis

Theory vs. Real Data – Budyko curves across the world's catchments



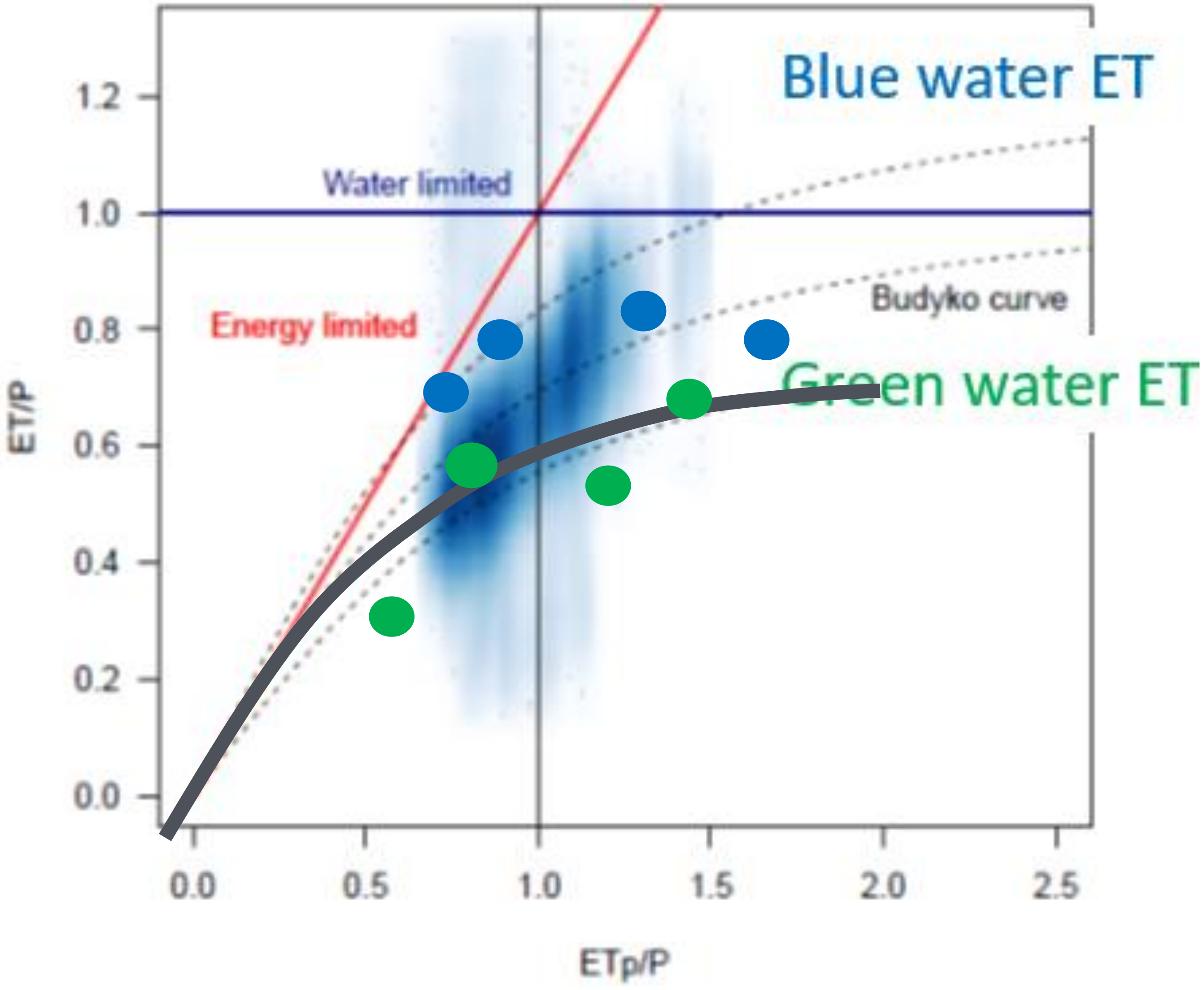
Budyko Hypothesis

Reference	Equation: F=E/P =	Background/Assumptions
Schreiber [1904]	$1 - \exp(-\phi)$	Schreiber [1904] suggested the equation without explicit knowledge of the underlying physical principles
Ol'Dekop [1911]	$\phi \cdot \tanh(1/\phi)$	Ol'Dekop [1911] revisited Schreiber [1904] to have an improved empirical fit for several Russian river basins.
Pike [1964]	$\frac{E_P}{\sqrt{P^2 + E_P^2}}$	Modification of Turc [1954] to better fit of inter-annual data of 4 catchments in Malawi
Budyko [1948; 1974]	$\sqrt{\phi \cdot \tanh\left(\frac{1}{\phi}\right) \cdot (1 - \exp(-\phi))}$	Approximate geometrical mean of Schreiber [1904] and Ol'Dekop [1911], that introduced R_n for the aridity approximations
Fu [1981] and Zhang et al. [2004]	$\frac{1 + \omega\phi}{(1 + \omega\phi + \phi^{-1})}$	ω is dimensionless free parameter without any a priori physical meaning, equation was derived by Fu [1981] and revisited by Zhang et al. [2004]
Turc [1954] Mezentsev [1955], Choudhury [1999], Yang et al. [2008]	$\frac{1}{(1 + \phi^{-n})^{1/n}}$	n is a dimensionless free parameter without any a priori physical meaning, Mezentsev [1955] provided an ad-hoc solution of the derivative dE/dP = 1-$(E/E_P)^n$, obtained by Bagrov [1953]. Mezentsev used 35 catchments of the Siberian plateau to obtain n = 2.3 Yang et al. [2008] provided the corresponding analytical solution, independently from Mezentsev [1955].
Zhang et al. [2001]	$\frac{1 + \omega\phi}{(1 + \omega\phi + \omega)^{-1}}$	ω is the plant available water coefficient, empirical approach
Porporato et al. [2004]	$1 - \frac{\phi\gamma^{\gamma/\phi - 1}\exp(-\gamma)}{\Gamma\left(\frac{\gamma}{\phi}\right) - \Gamma\left(\frac{\gamma}{\phi}, \gamma\right)}$	γ contains the average rainfall depth and the soil water holding capacity, equation based on a stochastic model
Donohue et al. [2012]	$\frac{1}{(1+\phi^{-n})^{\frac{1}{n}}}$, with $n = \frac{0.21\kappa Z_e}{\alpha} + 0.6$	Budyko-Choudhury-Porporato (BCP) model incorporating estimates of plant-available water holding capacity (κ), mean storm depth (α) and effective rooting depth (Z_e)

Velpuri et al. (2017) uses an Energy balance-water balance modeling approach to Estimate blue and green ET

Budyko Hypothesis with in WaPOR WA

- Uses Evaporative index
- If ET/P <= 1.0,
  - ET_{green} = ET
  - ETblue = 0
- If ET/P > 1.0,
  - ET_{green} = P
  - $ET_{blue} = ET_a - ET_{green}$



EXERCISE:

Separation of ET into Blue, green

Exercise: Partition ET into green and blue ET

Objective:

- To understand how to use Budyko equation to partition ET into green and blue ET.

Instructions:

Use the data provided in the excel

- **Step 1:** Derive Aridity index (ETo/P) for January

$$\frac{E}{P} = \left[\frac{E_p}{P}\tanh\left(\frac{P}{E_p}\right)(1 - \exp\left(-\frac{Ep}{P}\right))\right]^{1/2}$$

- **Step 2:** Derive E/P ration using **Budyko equation** for January

Exercise: Partition ET into green and blue ET

Objective:

- To understand how to use Budyko equation to partition ET into green and blue ET.

Instructions:

Use the data provided in the excel

- **Step 3:** Compute ETgreen (E/P * P) for January

- **Step 4:** Compute ETblue (ET-ETgreen) for January

Exercise: Partition ET into green and blue ET

Objective:

- To understand how to use Budyko equation to partition ET into green and blue ET.

Instructions:

Use the data provided in the excel

- **Step 5:** Repeat Step 1 to Step 4 for all months

- **Step 6:** Generate annual P, ET and ETo and Repeat Step 1 to Step 4 annual data

- **Step 7:** Compute ETgreen and ETblue as the sum of each month

Partition ET into green and blue ET

Questions for discussion:

- Based on the ETgreen and ETblue values, what are some obvious errors and why?
- Why is Aridity index closer to 1.0 in some months and away from 1.0 for other months?
- What is the difference between the results obtained from Step 6 and Step 7? Which approach is the more appropriate?

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THANK YOU FOR YOUR ATTENTION

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