Misunderstanding and Misconceptions in Irrigation Water Management

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Issue 1: Understanding the True Meaning of Deficit Irrigation

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The Issue of Deficit Irrigation

Researchers reported obtaining equal yield at deficit irrigation (e.g. at 50% or 60% or 70%,...i.e. < 100% of full irrigation requirement) to the yield obtained when they applied 100% full irrigation requirement.

The question is:

Is the deficit irrigation really a deficit or just it is the actual requirement and the Full irrigation requirement was exaggerated due to the over estimation by the method used to determine the crop water requirement?

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Crop Water Requirement determination

1. Equations based on meteorological data (temperature, energy or combination) & empirical equations
2. Soil Measurements (moisture content, soil moisture deficit, SMD, zero flux plain, moisture profiles , soil water balance, etc.
3. Plant Measurements: sap flow
4. Lysimeters (lysimeter is a measuring device to measure the amount of actual evapotranspiration released by plants Lysimeters are of two types: weighing and non-weighing.
5. Measurements (direct/indirect) of the evaporation flux; Class A pan, Bown ration, Eddy Covariance, Scintillometers. The accuracy of all those methods and the scale they represent are of great importance.

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Deficit Irrigation

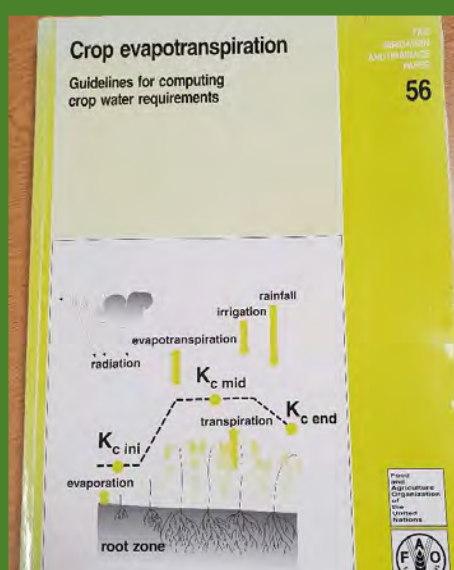
Usually defined as a reduced irrigation water amount that represents a % of the Full Crop Water Requirement CWR.

CWR can be measured (e.g. Lysimeters, SMD, etc.) or calculated from equations such as FAO-56 Penman- Monteith equation as:

Full CWR = $$ET_c = ET_o(K_{cb} + K_e)$$

Deficit Irrigation= % < 100 of ETc (e.g. 90% ETc, 50% ETc, …)

FAO Modified Penman-Monteith Equation



Penman-Monteith Evapotranspiration (ET)

In presence of stomata / canopy surface resistance data, one could use the widely used equation Penman-Monteith (1965) in the following form:

where r_s and r_a are the bulk surface and aerodynamic resistances (s m^{-1}).

$$\lambda E_p = \frac{\Delta R_n + \rho C_p \frac{(e_s - e)}{r_a}}{\Delta + \gamma (1 + \frac{r_s}{r_a})}$$

The Penman-Monteith Equation was a unique equation as it did include the presence of the plant instead of focusing only on weather data (radiation or temperature) to determine ET. However, the difficulty in getting the plant parameter (canopy resistance) confined it to a limited application by mostly academics.

Evapotranspiration

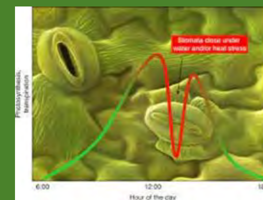
Penman - Monteith, FAO-56 (1998)version

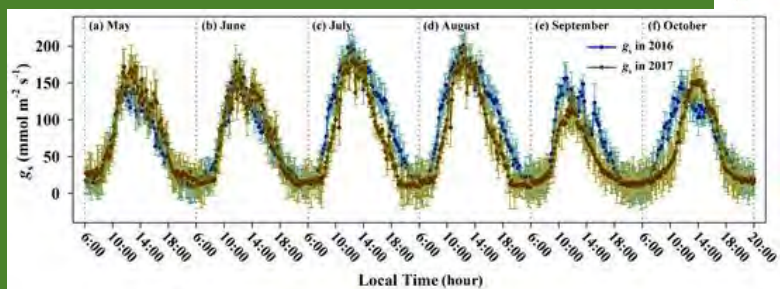
$$ET_o = \frac{0.408 \Delta (R_n - G) + \gamma \frac{900}{T + 273} U_2 (e_s - e_a)}{\Delta + \gamma (1 + 0.34 U_2)}$$

$$ET_c = ET_o (K_{cb} + K_e)$$

rs = 70s/m

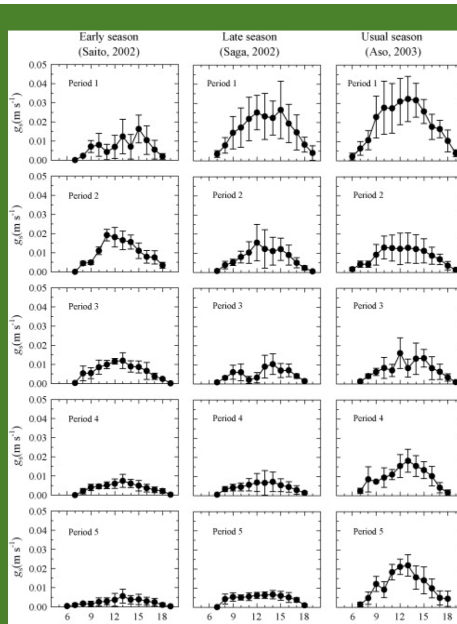
Tuo Han, Qi Feng, Tengfei Yu, Xiaomei Yang, Xiaofang Zhang and Kuan Li Characteristic of Stomatal Conductance and Optimal Stomatal Behaviour in an Arid Oasis of Northwestern China. Sustainability 2022, 14(2), 968; https://doi.org/10.3390/su14020968

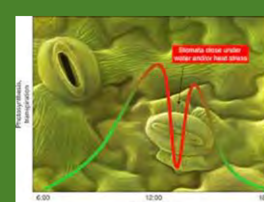




Diurnal courses of stomatal conductance (gs, mmol m−2 s−1) in three sunny days from May to October in 2016 and 2017, respectively. (a–f) represent datasets from May to October, respectively. The bars represent the standard deviations of the mean

Atsushi Maruyama, Tsuneo Kuwagata, Diurnal and seasonal variation in bulk stomatal conductance of the rice canopy and its dependence on developmental stage, Agricultural and Forest Meteorology, Volume 148, Issues 6–7, 2008, Pages 1161-1173, ISSN 0168-1923,





https://doi.org/10.1016/j.agrformet.2008.03.001

Field Instrumentation-accurate estimation of crop water requirement

COSMOS

Scintillometer

Eddy Covariance

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www.water4crops.org

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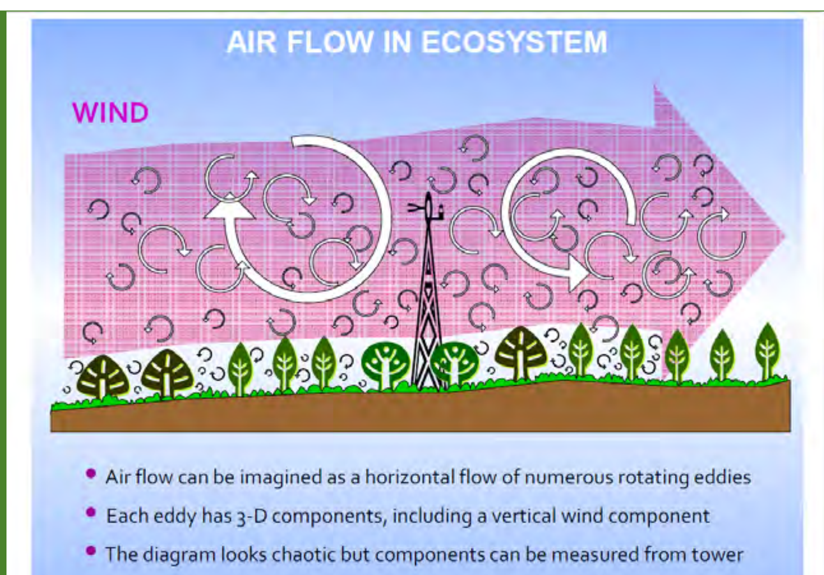

LI-COR Biosciences | Brief Guide To Eddy Covariance Measurements : https://www.licor.com/env/pdf/eddy_covariance/Brief_Intro_Eddy_Covariance.pdf

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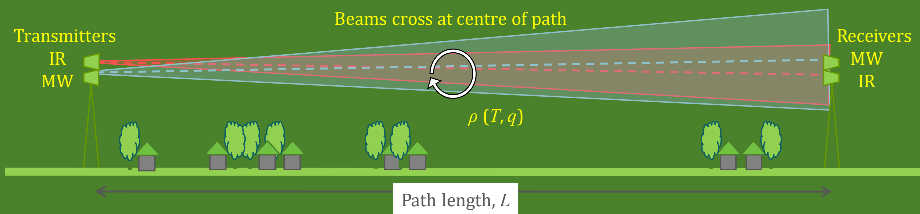
Scintillometry at multiple wavelengths

Combine optical/infra-red with micro/radio-wave scintillometer – sensitive to both temperature and humidity fluctuations.



Up to 10 km Path Length

Refractive index changes because of air density differences, heat T and relative humidity/moisture, q.
Scintillometry uses these changes in the refractive index of air to derive surface fluxes.

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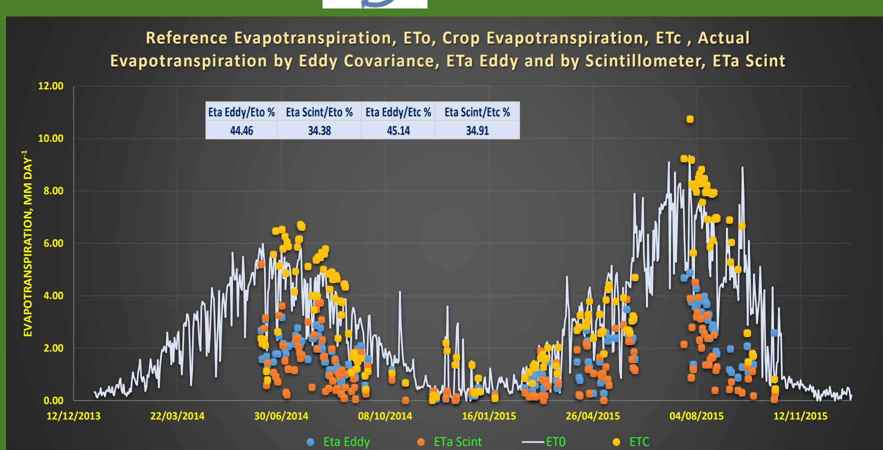

Comparison between actual evapotranspiration measured by Eddy Covariance and Scintillometer, reference evapotranspiration estimated from Penman-Monteith equation and crop evapotranspiration calculated from ETo and the weighted mean of the crop coefficient Kc.

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Conclusion of the Eta measurements:

The ETc and ETo obtained by Penman-Monteith equation, showed higher values than those of ETa obtained by Eddy Covariance and Scintillometer.

On average the actual evapotranspiration of Eddy Covariance and Scintillometers for the cropping seasons 2014 and 2015 represented 45% and 35% of the ETo and ETc, respectively. These are quite significant differences.

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- Calculating the reference evapotranspiration, ETo, or the crop evapotranspiration, ETc, from meteorological data, produces potential evapotranspiration that would represent the atmospheric demand for water rather than the crop demand for water.
- Accurate crop water requirement should be based on crop demand rather than on atmospheric demand for water.

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- **Another benefit is, these <u>modern technologies of measuring the actual evapotranspiration do not need the crop coefficient Kc</u>, obtaining Kc is a major problem to many irrigation practitioners.**
- **Other methods for measuring actual evaporation can also be useful (e.g. weighing lysimeters, etc.) but be aware, the scale is too small.**

- **<u>If Eddy Covariance or Scintillometers are not available or not affordable,</u> short term monitoring of actual evaporation using other methods could be used to derive a relationship with the commonly used Eto or Etc that are easily obtainable from the standard weather stations.**

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COSMOS soil moisture sensors, "Area based"

- **Large scale: 300-700 m radius of sensitivity**
- **Non-invasive, completely passive**
- **Uses background fast neutrons generated by Cosmic rays, which are scattered (slowed) by H atoms.**
- **Gives more representative soil moisture based on area not on a single point.**
- **Could help to obtain the SMD to estimate irrigation water requirement from more area representative integrated soil moisture and avoiding the point scale measurements / heterogeneity.**

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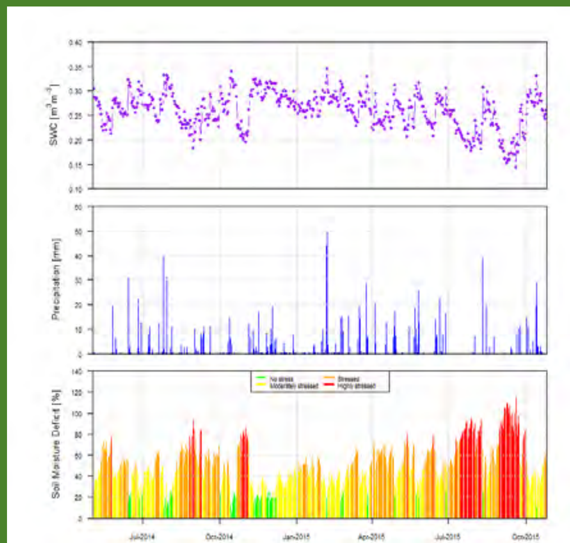

COSMOS soil moisture

The different level of water stress is based on FAO guidelines as given in Allen et al. (1998): SMD ≤ 25% no water stress, 25 < SMD ≤ 50% moderately water stressed, 50 < SMD ≤ 75% water stressed and SMD > 75% highly water stressed

Water content adjusted for biomass for 60 cm effective depth as verified and tested by field measurements.

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Publications

Ragab, R, Evans, J G, Battilani, A, and Solimando, D. (2017) Towards Accurate Estimation of Crop Water Requirement without the Crop Coefficient K_c: New Approach Using Modern Technologies. *Irrig. and Drain.*, 66: 469–477. doi: 10.1002/ird.2153.

Ragab, R, Evans, J G, Battilani, A, and Solimando, D. (2017) The Cosmic-ray Soil Moisture Observation System (Cosmos) for Estimating the Crop Water Requirement: New Approach. *Irrig. and Drain.*, 66: 456–468. doi: 10.1002/ird.2152.

Wiley issued a press release about the two studies

A note on Water Use Efficiency and water Productivity
http://www.water4crops.org/wp-content/uploads/2014/08/RR_Water-use-efficiency-and-water-productivity.pdf

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Issue 2: Understanding the difference between the Water Use Efficiency and the Water Productivity

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Water Use Efficiency and Water Productivity

Some agronomists used the terms “water use efficiency” and “water productivity” interchangeably.

Back in the 1960’s authors tended to use ‘water use efficiency’ to describe ‘water productivity’.

Since the early 1980’s, high impact journals no longer accept papers where ‘water use efficiency’ and ‘water productivity’ are not used correctly.

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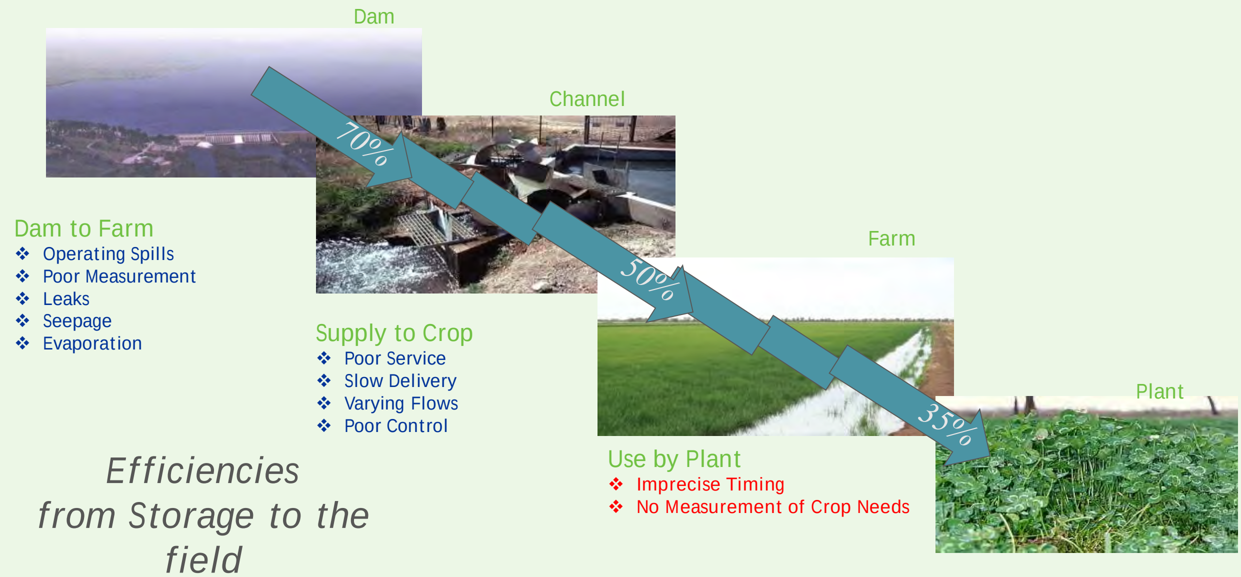
Irrigation - a managed water cycle



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WUE and WP

In accordance with the definition proposed by the International Commission on Irrigation and Drainage, efficiency has different components:

1. Storage efficiency Es = *Vd/ Ve*

Ratio between the volume diverted for irrigation (Vd) and the volume entering a storage reservoir (Ve) for the same purpose.

2. Conveyance efficiency Ec= *Vp/ Vd*

Ratio between the volume of water delivered to irrigation plots (Vp) & the volume diverted from the supply source (Vd).

3. Irrigation efficiency Eu = *Vu / Vp*

Ratio between the volume of water used by plants throughout the evapotranspiration process (Vu) and the volume that reaches the irrigation plot (Vp). Note that Vu is equal to the volume of evapotranspiration by plants minus the volume of effective rainfall.

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Water Use Efficiency (WUE)

Efficiency of any process = (useful output/total input) x 100
Note: output an input need to have the same units

Water use efficiency in agriculture = the % of water supplied to the plant that is effectively taken up by the plant,
i.e. that is not lost due to drainage, bare soil evaporation or interception.

If, for example, 10mm water is added to the plant and the plant used 8 mm through root water uptake and lost by transpiration while 2mm water is lost through drainage below the root zone or via bare soil evaporation from the surface then the water use efficiency is (8 mm / 10 mm) x 100 = 80%

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Water Productivity (WP)

Productivity, in general, refers to what you can produce from a unit of input.

Note: Input and output don not need to have the same units

Water productivity in agriculture:

is the crop yield produced per unit of water supplied,
e.g. 50 kg grains per 1 m^3 of water.

Modern agriculture aims to increase yield production per unit of water used, both under rain-fed and irrigated conditions.

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Product	Water productivity			
	Kilograms per cubic meter	Dollars per cubic meter	Protein grams per cubic meter	Calories per cubic meter
Cereal				
Wheat ($0.2 per kilogram)	0.2–1.2	0.04–0.30	50–150	660–4,000
Rice ($0.31 per kilogram)	0.15–1.6	0.05–0.18	12–50	500–2,000
Maize ($0.11 per kilogram)	0.30–2.00	0.03–0.22	30–200	1,000–7,000
Legumes				
Lentils ($0.3 per kilogram)	0.3–1.0	0.09–0.30	90–150	1,060–3,500
Fava beans ($0.3 per kilogram)	0.3–0.8	0.09–0.24	100–150	1,260–3,360
Groundnut ($0.8 per kilogram)	0.1–0.4	0.08–0.32	30–120	800–3,200
Vegetables				
Potatoes ($0.1 per kilogram)	3–7	0.3–0.7	50–120	3,000–7,000
Tomatoes ($0.15 per kilogram)	5–20	0.75–3.0	50–200	1,000–4,000
Onions ($0.1 per kilogram)	3–10	0.3–1.0	20–67	1,200–4,000
Fruits				
Apples ($0.8 per kilogram)	1.0–5.0	0.8–4.0	Negligible	520–2,600
Olives ($1.0 per kilogram)	1.0–3.0	1.0–3.0	10–30	1,150–3,450
Dates ($2.0 per kilogram)	0.4–0.8	0.8–1.6	8–16	1,120–2,240
Others				
Beef ($3.0 per kilogram)	0.03–0.1	0.09–0.3	10–30	60–210
Fish (aquaculture[a])	0.05–1.0	0.07–1.35	17–340	85–1,750

a. Includes extensive systems without additional nutritional inputs to superintensive systems.

Source: Muir 1993; Verdegem, Bosma, and Verreth 2006; Renault and Wallender 2000; Oweis and Hachum 2003, Zwart and Bastiaanssen 2004.

Productivity from a unit of water for selected commodities (Molden et al. 2010a)

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WUE and WP do exist

It should be clear in our mind that the terms WUE and WP do exist in real life, have different meanings but are interlinked, e.g. in order to increase the WP we need to increase the WUE, not the other way around.

There is a strong linkage between WUE and WP. Increase of WP follows the increase of WUE and other efficiencies such as weed control, fertilization, and pest and disease control.

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WUE and WP

Unlike water use efficiency, the productivity could refer to multi-use/user benefits from water use. For example, people using water for both irrigation and fisheries (Rice+shrimps) clearly contribute to their livelihoods and to the regional economy.

Productivity refers to the benefits of water (income, jobs, crop production) as a ratio of water used. Productivity is an expression of the bio-economic output from the gross amount of water used.

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Issue 3: Is adding Leaching Requirement to each irrigation necessary? or a wrong practice

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The Leaching Fraction Issue

Some Irrigation Practitioners automatically apply a Leaching Fraction to the total Irrigation Requirement.

For example, some practitioners add 15% extra water with each irrigation as a leaching fraction regardless the soil salinity level or crop tolerance level and without monitoring the soil salinity.

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Leaching Fraction as part of Irrigation Water Requirement

$$IR = [ET_O \times Kc] / E_i - R + LR$$

IR = irrigation requirements, mm/day,

ET_O = reference evapotranspiration, mm/day,

Kc = crop factor (Allen *et al.,*1998), factor,

E_i = irrigation efficiency, %,

R = water received by the plant from sources other than irrigation, for example rainfall, mm,

LR = amount of water required for the leaching of salts, mm.

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Issues related to Leaching Requirement

When? Only when salt concentration exceeds plant tolerance limit.

How :

- **By unavoidable irrigation inefficiency**
- **Occasional rain**
- **Apply fresh water seasonally (recommended)**
- **Apply fresh water after each irrigation (not recommended unless there is a great risk for the crop if no leaching considered)**

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Why we need an accurate estimate of crop water & Leaching requirement

Accurate estimate of Crop water requirement has impact ?

Adding more water = adding more salts (if irrigating with brackish/saline water)
= more leaching of nutrients & fertilizers
= decreasing soil and groundwater qualities
= decreasing water productivity and WUE
= Irrigating less area
= wasting water resource, labour, energy and money
= increasing drainage water volume

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Issue 4: There is no need to improve Irrigation Efficiency in the belief that what is lost upstream will be gained downstream

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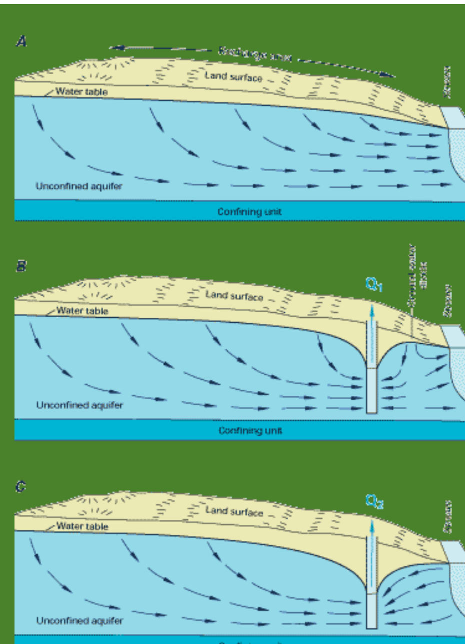
1. This assumes that the subsurface layers are homogeneous and no barriers or change in the geology. What is lost upstream may not appear at downstream.

2. Even if is gained at downstream, it will be with lower quality due to the leaching of salts and agro-chemicals.

3. It might take long time especially in semi-arid and arid regions. Sub-surface flow is generated only when the subsurface soil layer is saturated first.

4. In regions with deep groundwater, this could take a long time to reach the aquifer.



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UPSCAPE Project:
Upscaling Catchment Processes for Sustainable Water Management in Peninsular India

Objectives of research:
Understand the influence of small-scale water management interventions on basin scale processes and decision-making

Geographical setting:
South India, focussing on River Cauvery

Funding programme:
Newton Bhabha Fund -
Sustaining Water Resources Programme

Timescale:
3 years

Project members
CEH, BGS, University of Dundee, IISC Bangalore, ICRISAT, ATREE.
CEH Staff: Gwyn Rees, Helen Houghton-Carr, Virginie Keller, Mike Simpson, Nathan Rickards, Ross Morrison, Ragab Ragab, Jonathan Evans, Mike Hutchins

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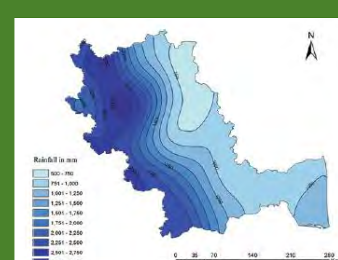
The Cauvery – A brief overview

- Basin area ~ 80,000 km^2
- Contentious inter-state river
- Predominantly rural
- Recent, rapid urban & economic growth (eg. Bangalore & Coimbtore)
- P gradient W-E >3000 – 500 mm.a^{-1}
- Availability of WR highly variable
- Significant WRM challenges at local, catchment & basin-scales

- ❑ Average Annual Rainfall = 813 mm
- ❑ Soils: Red Soil, Red Sandy Soil & Black Cotton Soil
- ❑ Crops: Paddy, Coconut, Horticulture crops, Vegetables
- ❑ Villages covered: Nilakottai ‘tehsil’ and Nilakottai block



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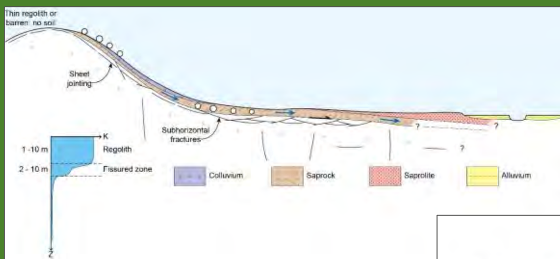


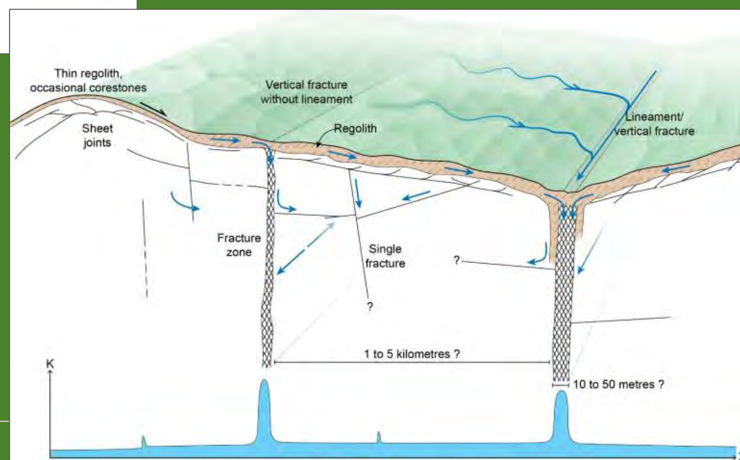
Bangalore Plateau

- Regolith: mainly saprock; 5-10 m thick. Saprolite – with clay – only on flat ground. Sharp lower boundary with fissured layer. Lower boundary regular surface (no great thickness variations).

Bangalore Plateau

Fractures

- Sheet joints up to 5-20 m bgl = fissured layer;
- Background jointing = poor: widely spaced fractures; depth unknown
- Major fracture zones; 10-50 m wide, with 1-5 km horizontal spacing, forming connected network.



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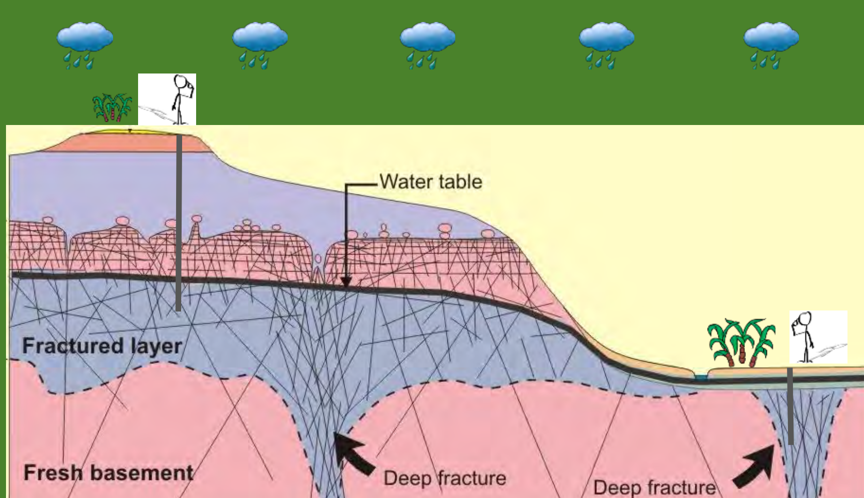
Hillslope modelling



After: **Maréchal, J.C. et al. 2009**. Indirect and direct recharges in a tropical forested watershed: Mule Hole India, Journal of Hydrology, 369 (3-4), 272-284.

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The Discontinuity of subsurface flow due to fractures and heterogeneity of the subsurface geology

Hydraulic tests (pumping tests) have been carried out in several boreholes of the watershed. The interpretation of the 18 hours pumping tests conducted indicated a no-flow boundaries (the groundwater level does not change in a borehole near to the borehole where the pumping test was carried out).

Fractures act as an underground barrier. The aquifer being disconnected, there is no base flow to the stream.

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Issue 5: Understanding the reasons for possible inaccuracy in Water Accounting:

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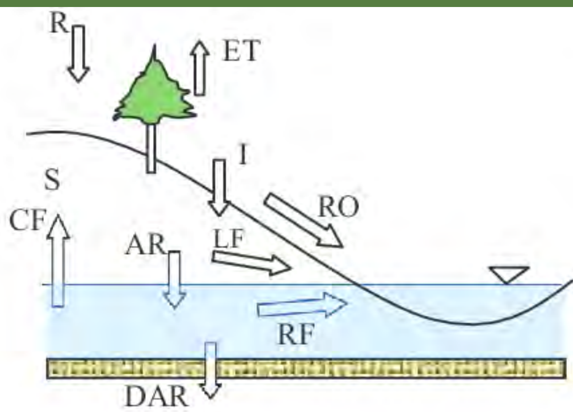

R=rainfall,
ET=evapotranspiration,
I=infiltration,
RO=runoff,
RF=return flow,
LF=Lateral flow
CF=capillary flow,
AR=aquifer recharge,
DAR=deep aquifer recharge
S=Soil moisture

Schematic illustration of the conceptual water balance in SWAT model.

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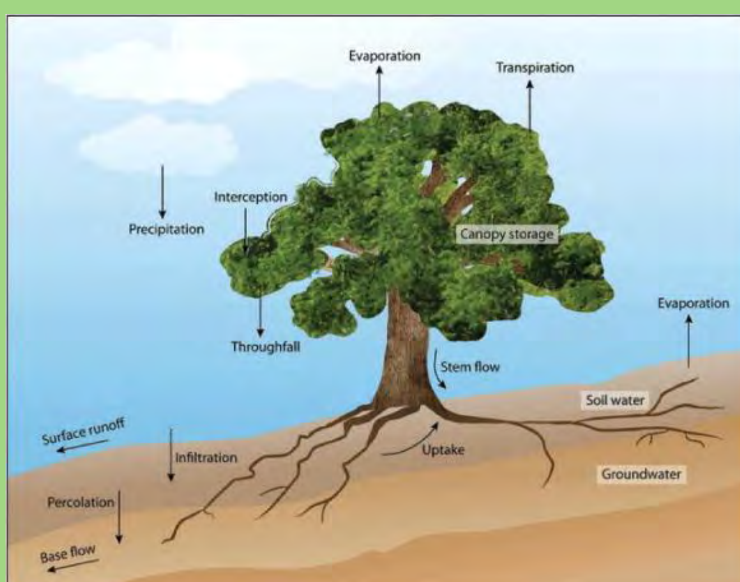

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The water balance means: The rate of water flow into a watershed minus the rate water flow out of a watershed equals the rate of change in the amount of water stored

$$P - R - G - ET = \Delta S$$

P is Precipitation, R is the runoff, G is the groundwater recharge, ET is the evapotranspiration

Issues could lead to inaccurate water accounting

P is total without excluding the rainfall intercepted by the vegetation Canopies. The amount of intercepted rainfall could be significant. We should use Pnet (P-Interception).

ET is mostly calculated from equation as Potential ET. We should use actual ET not potential.

R Groundwater Recharge is difficult to quantify and mostly estimated.

Quantifying the Groundwater Recharge

The correct estimate of natural recharge is a key element for the good management of groundwater resources.

Methods to quantify recharge: chloride mass balance, water table fluctuation, geophysical investigations, pumping tests and GW flow models.

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Issue 6: Understanding the reasons for inaccuracy and uncertainty of the modelling results

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Issues Related to Modelling

- Representation of the physical processes at field scale. Most of models are based on point scale equations.
- Most of models struggle with accounting for heterogeneity in soil and plant cover.
- Difficulties in calibration of models especially due to data adequacy / gaps, scale mismatch between model output and measurements.

Issues Related to Uncertainty in Model results

Uncertainty in Results could be attributed to:

- **Model assumptions, processes descriptions, mechanisms, mathematical formulation & the numerical scheme.**
- **In nature all processes operate simultaneously while in model they don't (they follow order of execution). If evaporation is calculated after infiltration, expect recharge, soil moisture to be different if the order of calculation was reversed.**
- **Linearity exists in model processes but not in nature where nothing is linear.**

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