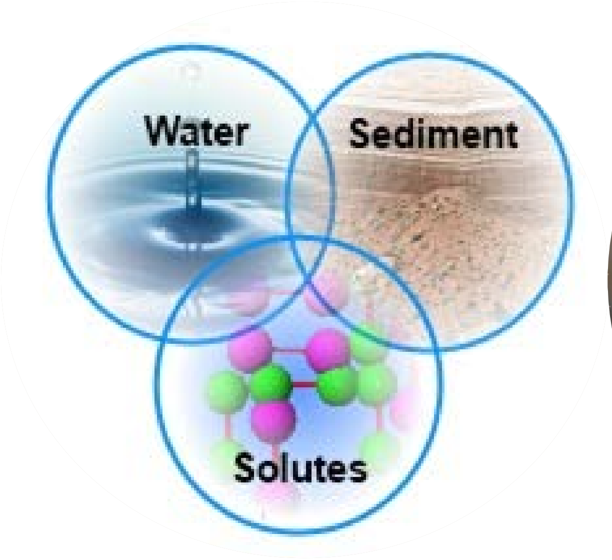
Root water uptake modelling

November 2013, Jos van Dam



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SLM
Soil Physics and
Land Management

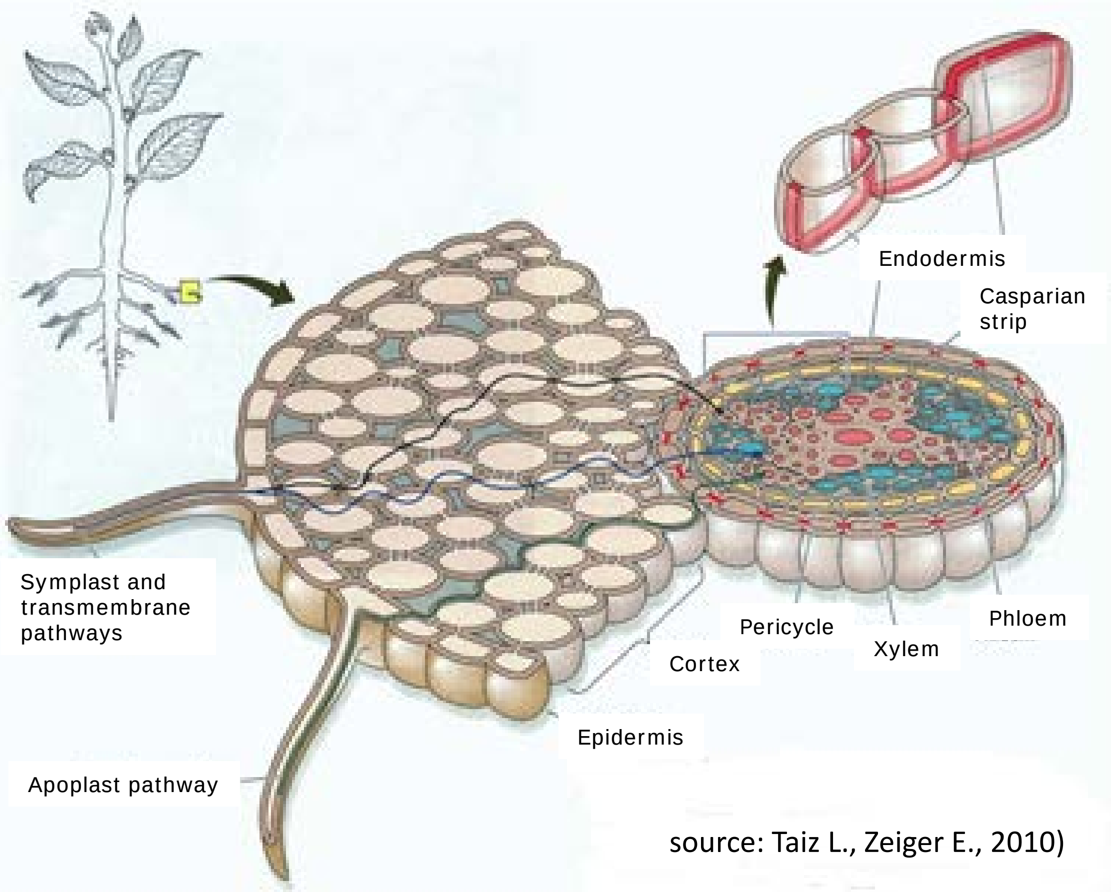
Root water uptake simulation

Root water uptake relevant for:

- Evapotranspiration
- Vegetation growth
- Soil moisture and oxygen conditions
- Groundwater recharge

In this presentation:

- Macroscopic concept
- Microscopic concept
- Current research issues



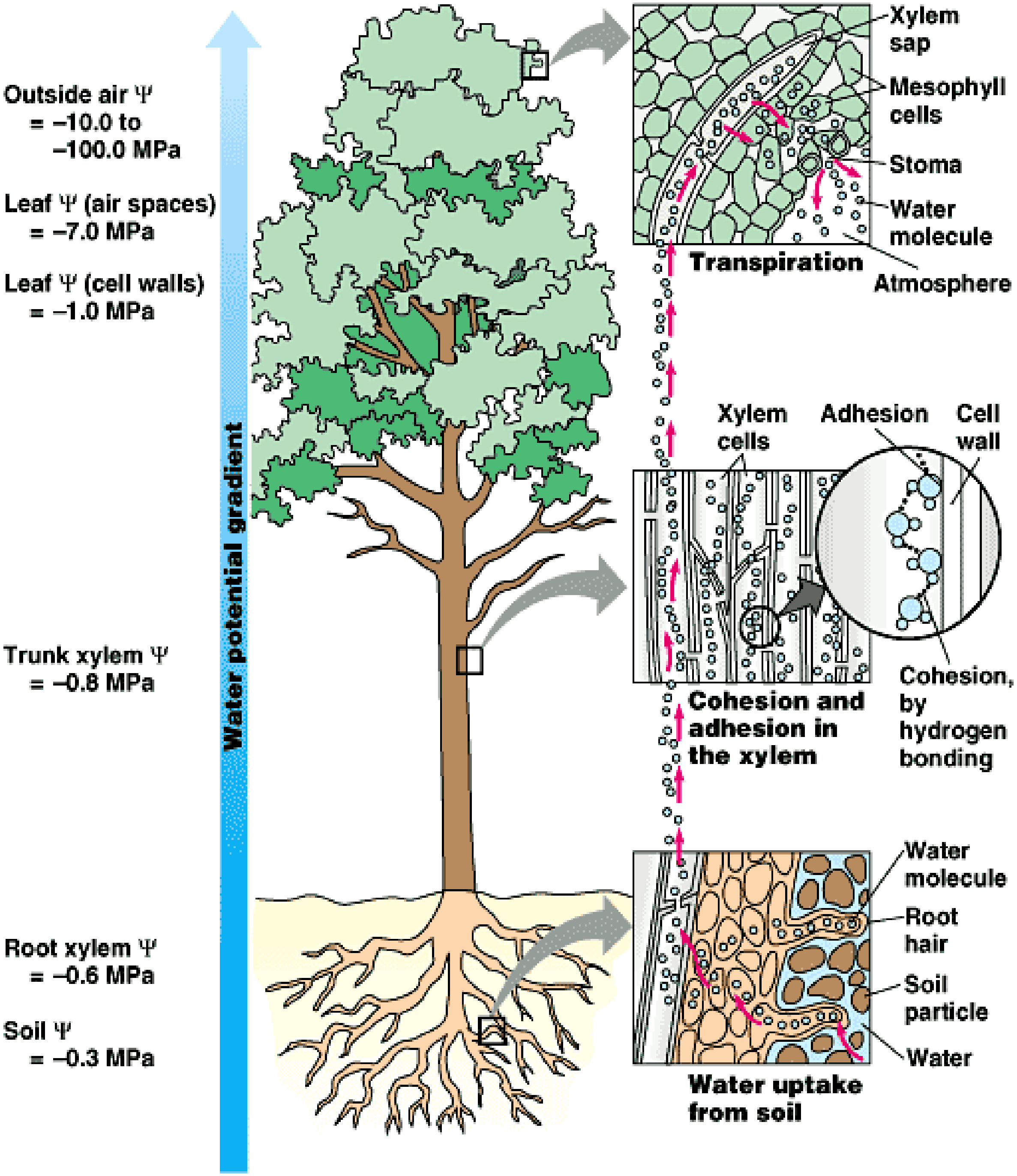
source: Taiz L., Zeiger E., 2010)

Hydraulic potential

Continuum of hydraulic potentials in soil-plant-atmosphere system

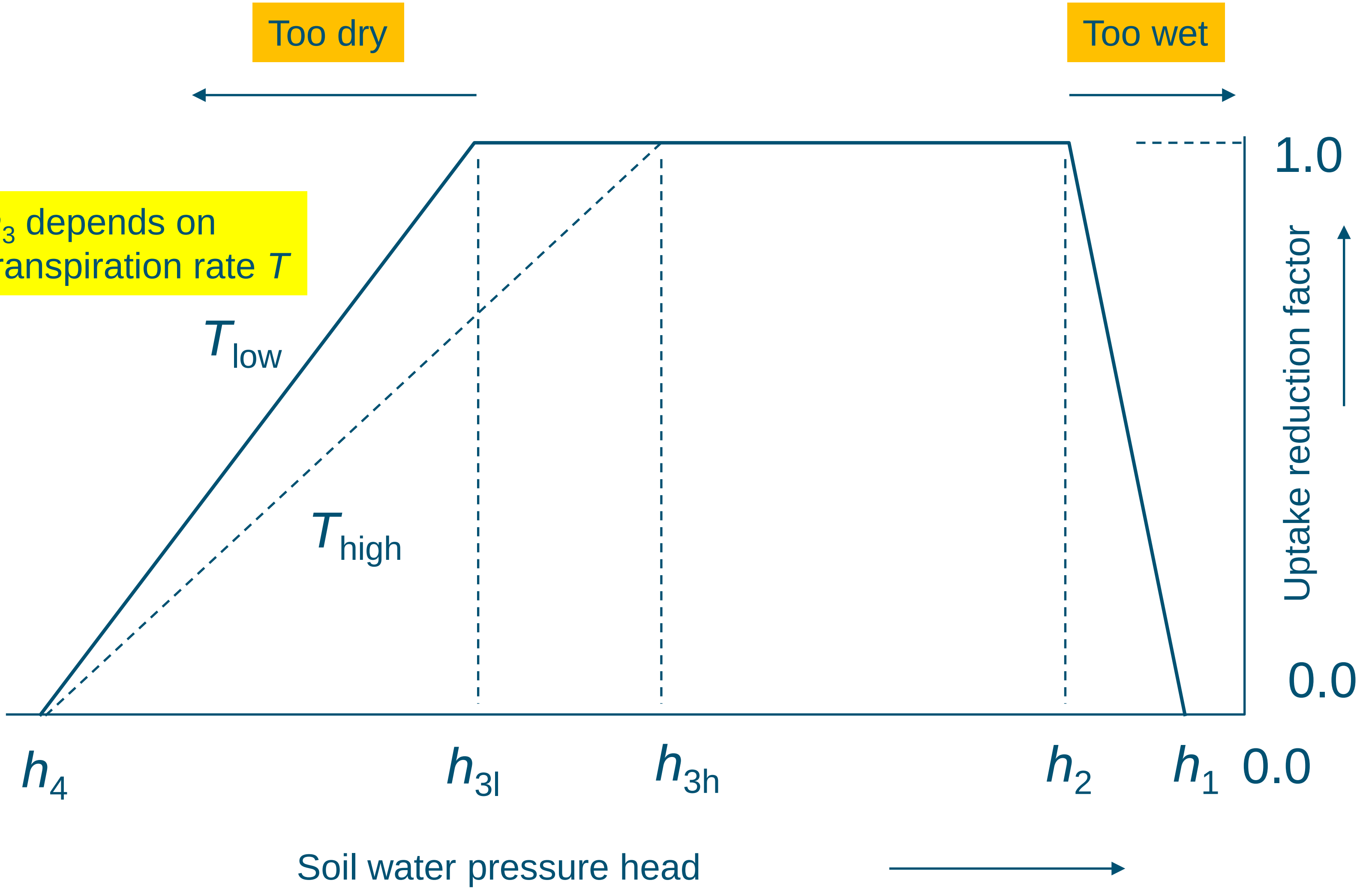
Total leaf transpiration equal to total root water uptake

1 MPa = 100 m pressure head



Common macroscopic reduction function

Soil is considered as a continuum of solids, roots, water and air



h_3 depends on transpiration rate T

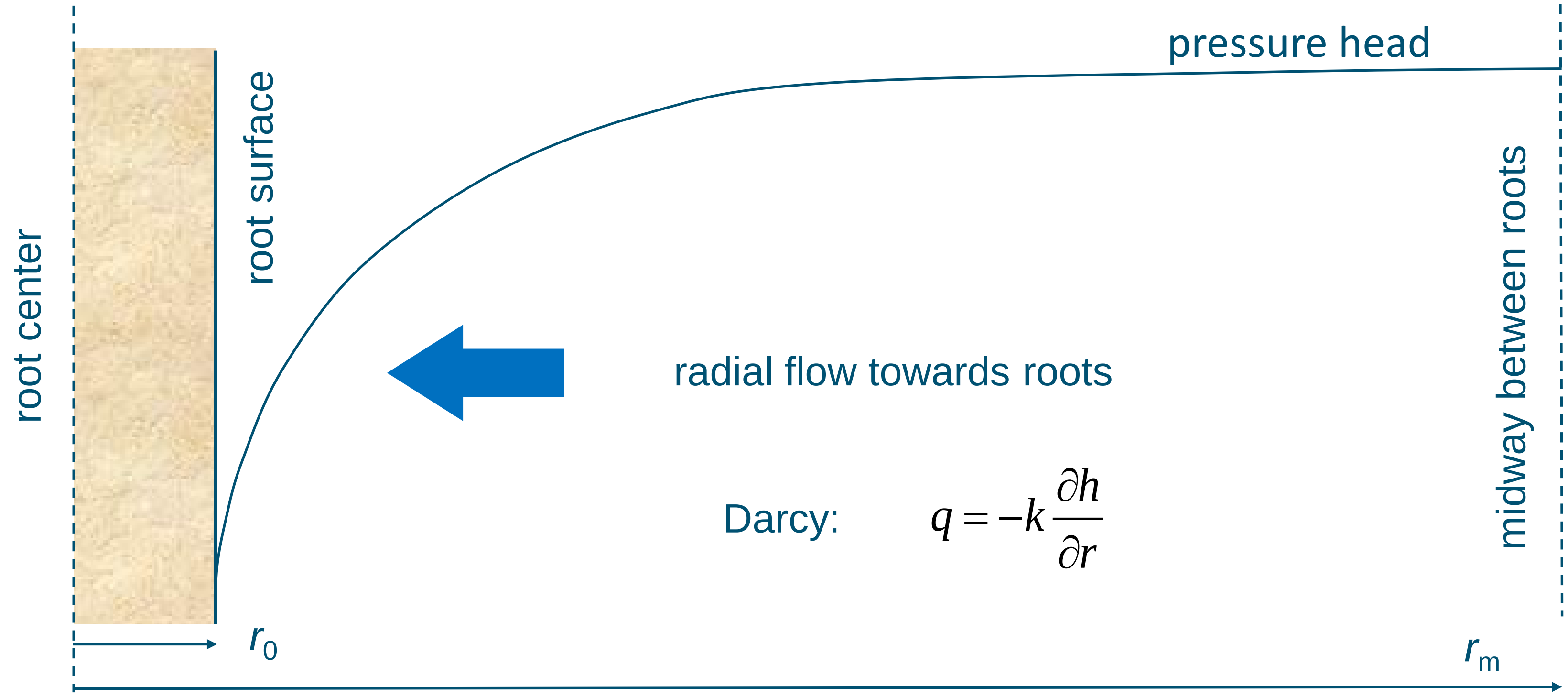
Critical pressure heads $h_1 - h_4$ are plant specific

Limitations macroscopic concept

- the limiting pressure head h_3 depends on the actual plant – soil – weather combination : therefore calibration is required
- relation between pressure head and reduction factor in the dry range might be strongly non-linear
- it is not clear how water and salt stress interact
- compensation of root water uptake is not included

Can we learn from microscopic root water uptake models?

Radial flow to single roots



radial flow towards roots

Darcy: $$q = -k \frac{\partial h}{\partial r}$$

near root surface:

flow area becomes small ➔ large flux density *q*
lower pressure head *h* ➔ small conductivity *k*

Therefore near root surface
very large gradients $\partial h / \partial r$

analytical solutions only with
gross simplifications

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Matric flux potential

q – flux density (m/d)
k – hydraulic conductivity (m/d)
h – pressure head (m)
r – radial distance (m)
M – matric flux potential (m^2/d)
h_w – plant wilting point (m)

Darcy:

$$q = -k \frac{\partial h}{\partial r}$$

Define matric flux potential:

$$M = \int_{h_w}^{h} k(h)\,\mathrm{d}h \quad \rightarrow \quad \partial M = k(h)\,\mathrm{d}h$$

In stead of considering very low values of hydraulic conductivity and very large differences of soil water pressure head, with the matric flux potential we only consider their product!

Linear relation between *q* and *M*:

$$q = -k(h)\frac{\partial h}{\partial r} = -\frac{\partial M}{\partial r}$$

With the matric flux potential we are able to derive robust analytical solutions for radial root water uptake

General root water extraction equation

Root extraction rate

Matric flux potential in soil

Matric flux potential at root surface

Derived general extraction equation:

$$S_z = \frac{4\left(M_{a,z} - M_{0,z}\right)}{r_{0,z}^2 - a_z^2\, r_{m,z}^2 + 2\left(r_{0,z}^2 + r_{m,z}^2\right)\ln \dfrac{a_z\, r_{m,z}}{r_{0,z}}}$$

Root radius

Average location

Radius of influence

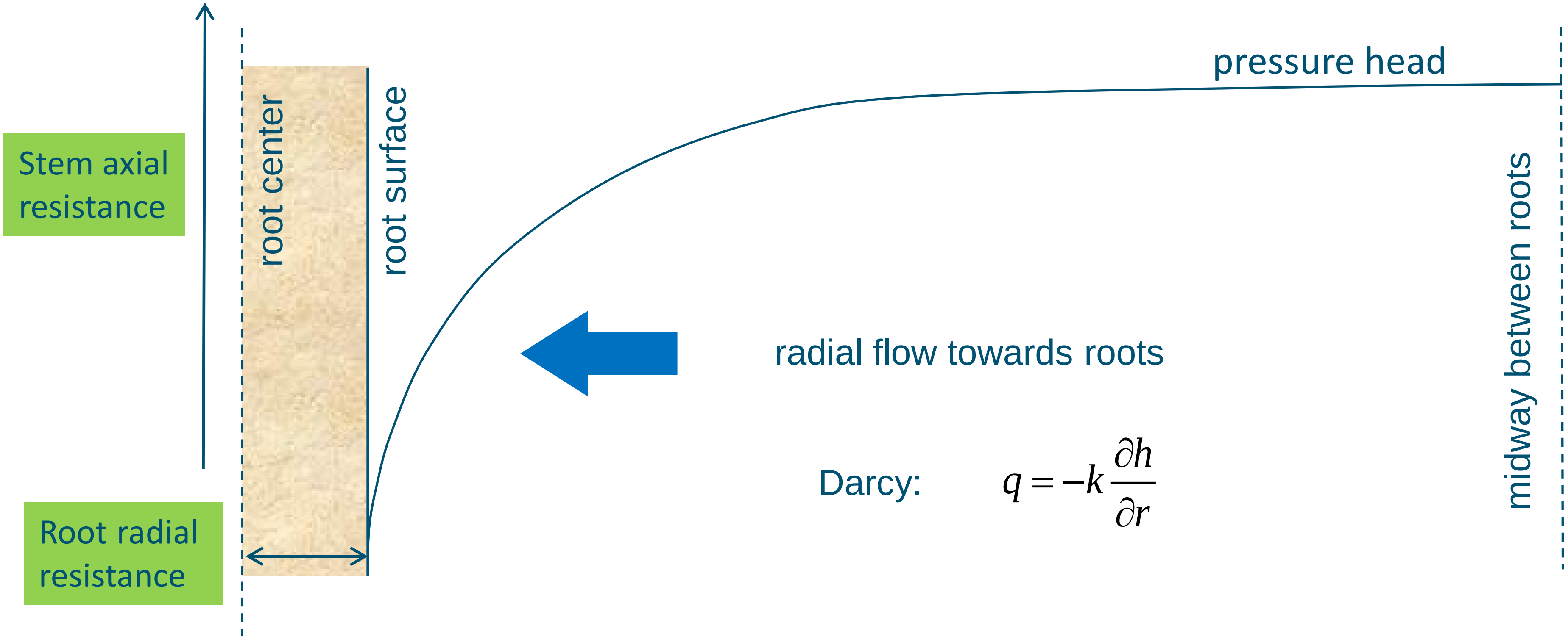
In a numerical model, soil hydraulic functions, root density and water content may vary with depth

Required input data are limited and physically defined:
- potential transpiration rate
- plant wilting point
- root length density profile
- root radius
- soil hydraulic functions (*h* – *θ* – *k* relations)

Improvement microscopic concept

Macroscopic concept	**Microscopic concept**
Critical pressure heads require calibration	Input data can be measured directly
Linear reduction in dry range adopted	Reduction in dry range follows from hydraulic potentials
Not clear how water and salt stress affect each other	Osmotic head due to salinity can be added to hydraulic potentials
No compensation of root water uptake	Compensation of root water uptake occurs automatically

Include flow in plant



Stem axial resistance

Root radial resistance

root center

root surface

pressure head

radial flow towards roots

Darcy: $q = -k \frac{\partial h}{\partial r}$

midway between roots

Assumed boundary condition: wilting point at soil surface

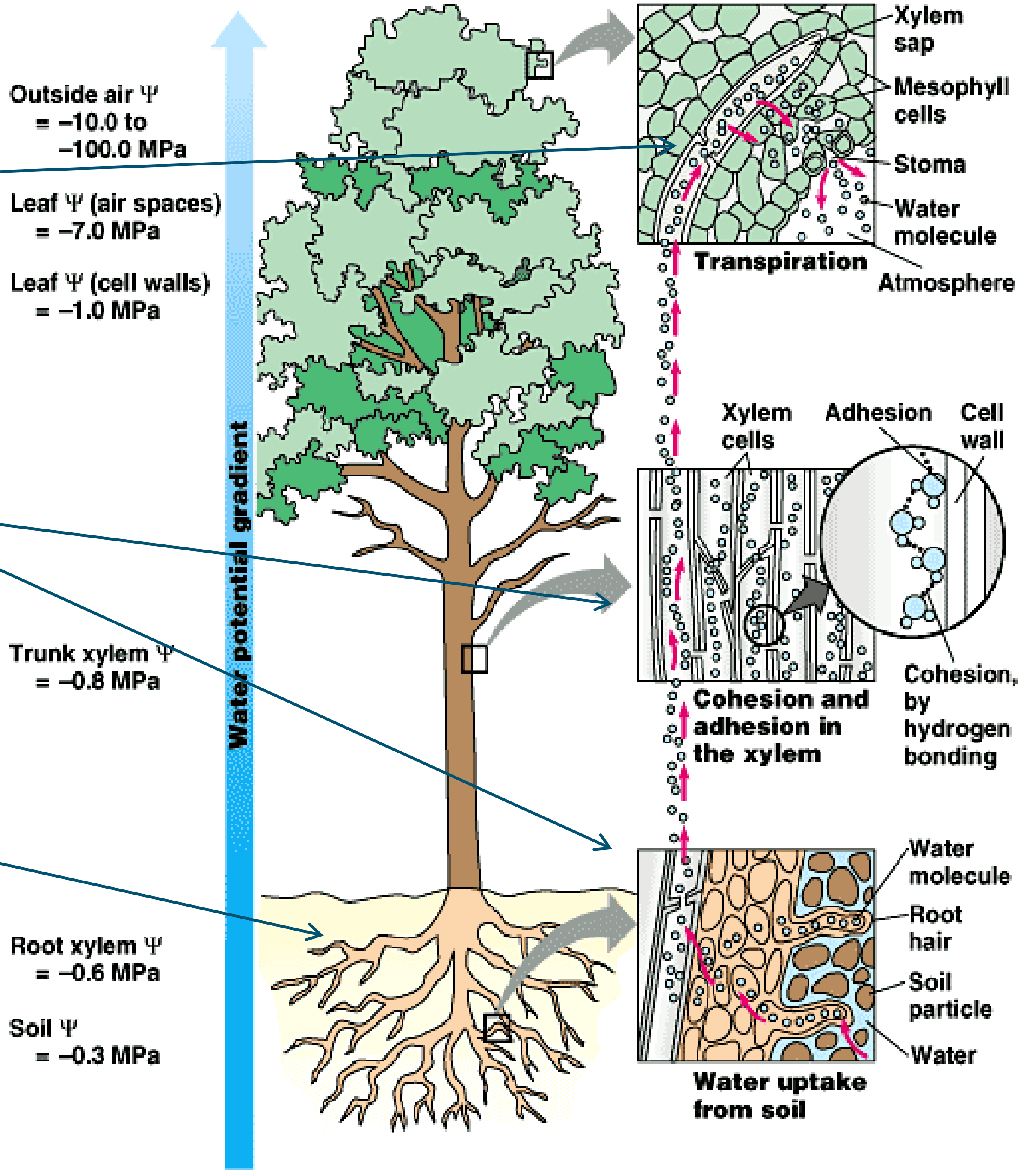
In case of low root density wilting point probably cannot be reached

Improvement: calculate root water extraction, taking into account root radial resistance, stem axial resistance and leaf water potential

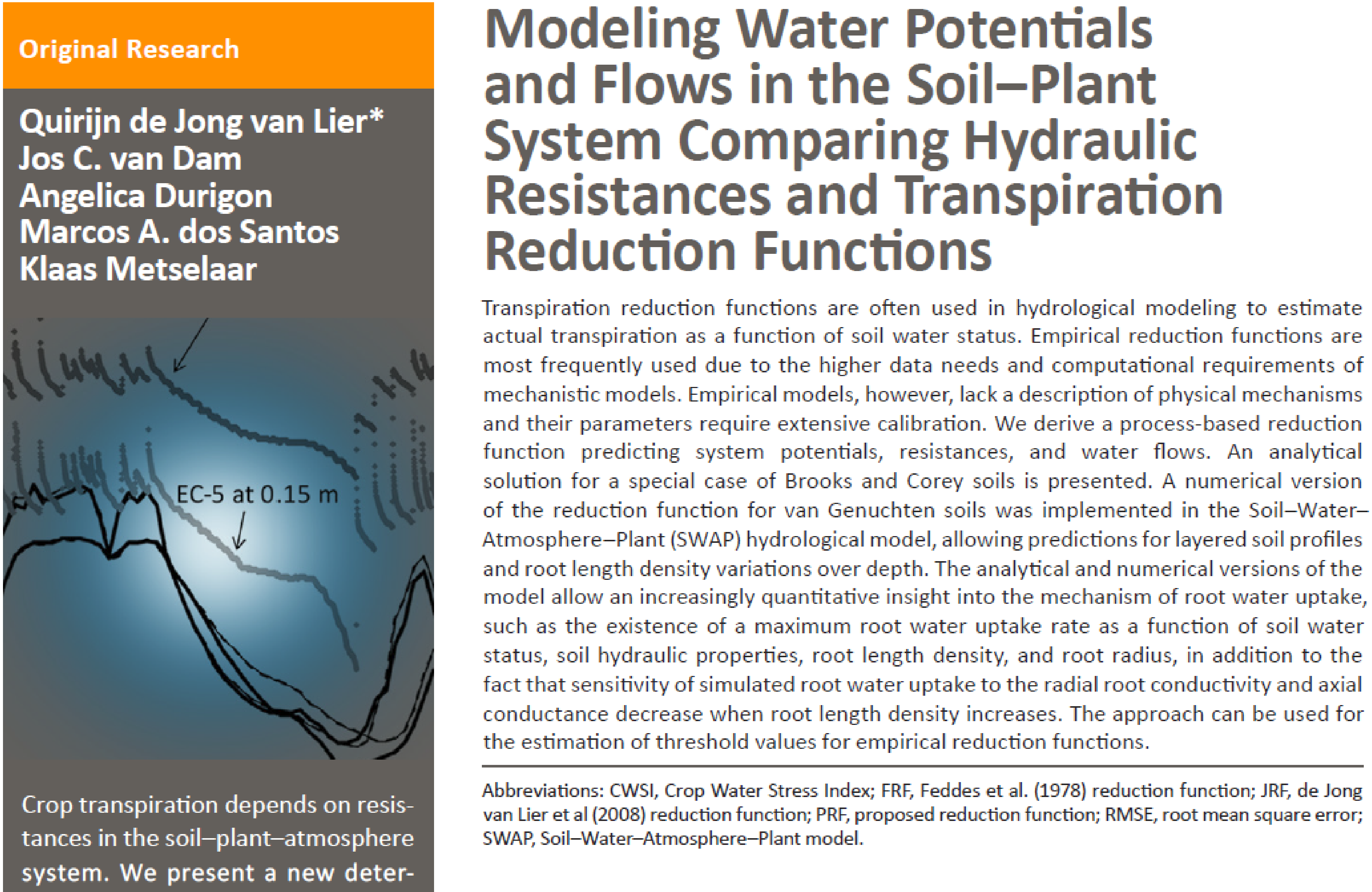
Instead of pressure head at root surface, boundary condition becomes leaf water potential

Include radial flow in roots and axial flow in xylem tubes

Most soil physical models stop at root surface



Research paper in Vadose Zone Journal, August 2013



Original Research

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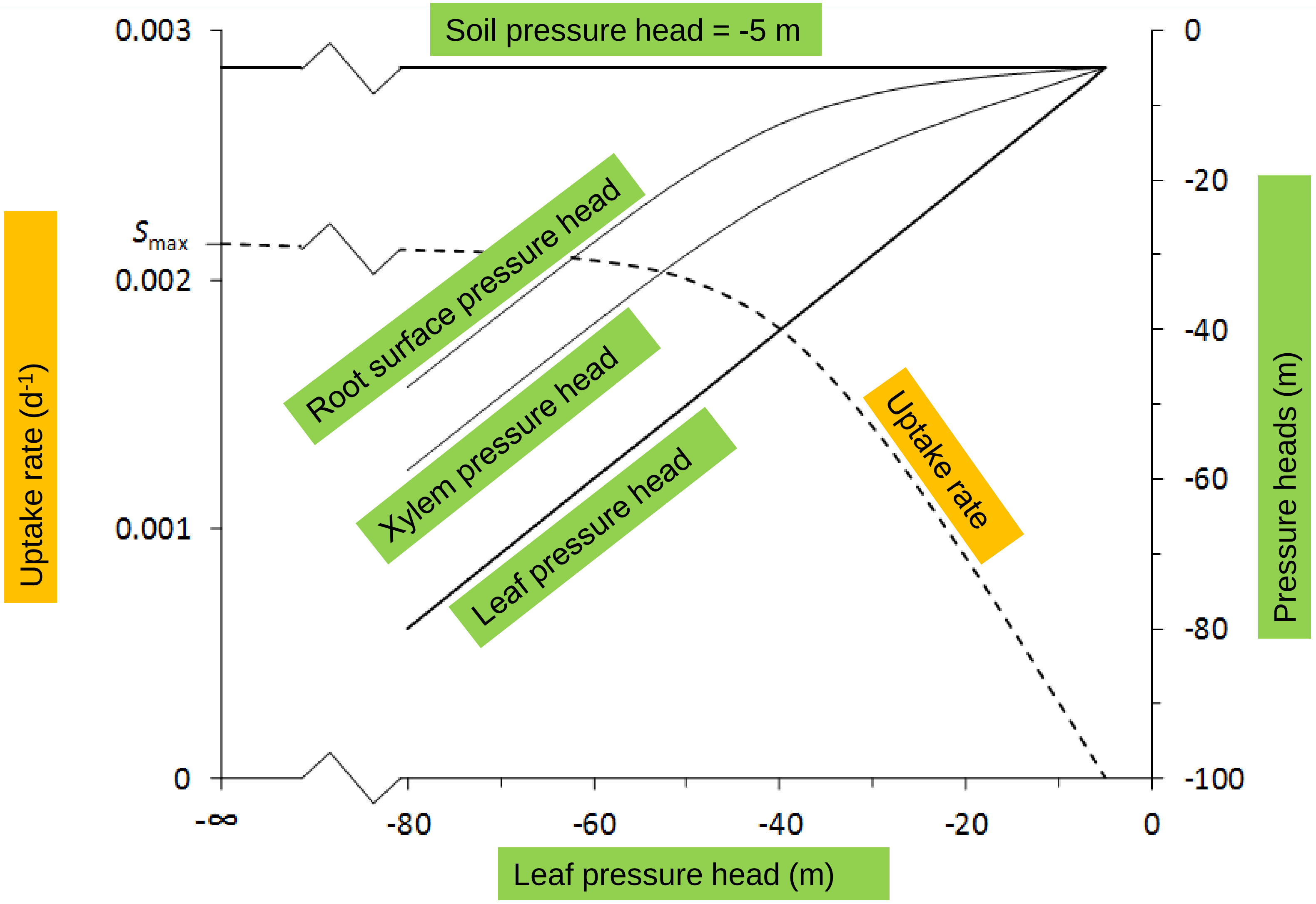
Crop transpiration depends on resistances in the soil–plant–atmosphere system. We present a new deter-

Modeling Water Potentials and Flows in the Soil–Plant System Comparing Hydraulic Resistances and Transpiration Reduction Functions

Transpiration reduction functions are often used in hydrological modeling to estimate actual transpiration as a function of soil water status. Empirical reduction functions are most frequently used due to the higher data needs and computational requirements of mechanistic models. Empirical models, however, lack a description of physical mechanisms and their parameters require extensive calibration. We derive a process-based reduction function predicting system potentials, resistances, and water flows. An analytical solution for a special case of Brooks and Corey soils is presented. A numerical version of the reduction function for van Genuchten soils was implemented in the Soil–Water–Atmosphere–Plant (SWAP) hydrological model, allowing predictions for layered soil profiles and root length density variations over depth. The analytical and numerical versions of the model allow an increasingly quantitative insight into the mechanism of root water uptake, such as the existence of a maximum root water uptake rate as a function of soil water status, soil hydraulic properties, root length density, and root radius, in addition to the fact that sensitivity of simulated root water uptake to the radial root conductivity and axial conductance decrease when root length density increases. The approach can be used for the estimation of threshold values for empirical reduction functions.

Abbreviations: CWSI, Crop Water Stress Index; FRF, Feddes et al. (1978) reduction function; JRF, de Jong van Lier et al (2008) reduction function; PRF, proposed reduction function; RMSE, root mean square error; SWAP, Soil–Water–Atmosphere–Plant model.

Example: Uptake rate as function of leaf pressure head



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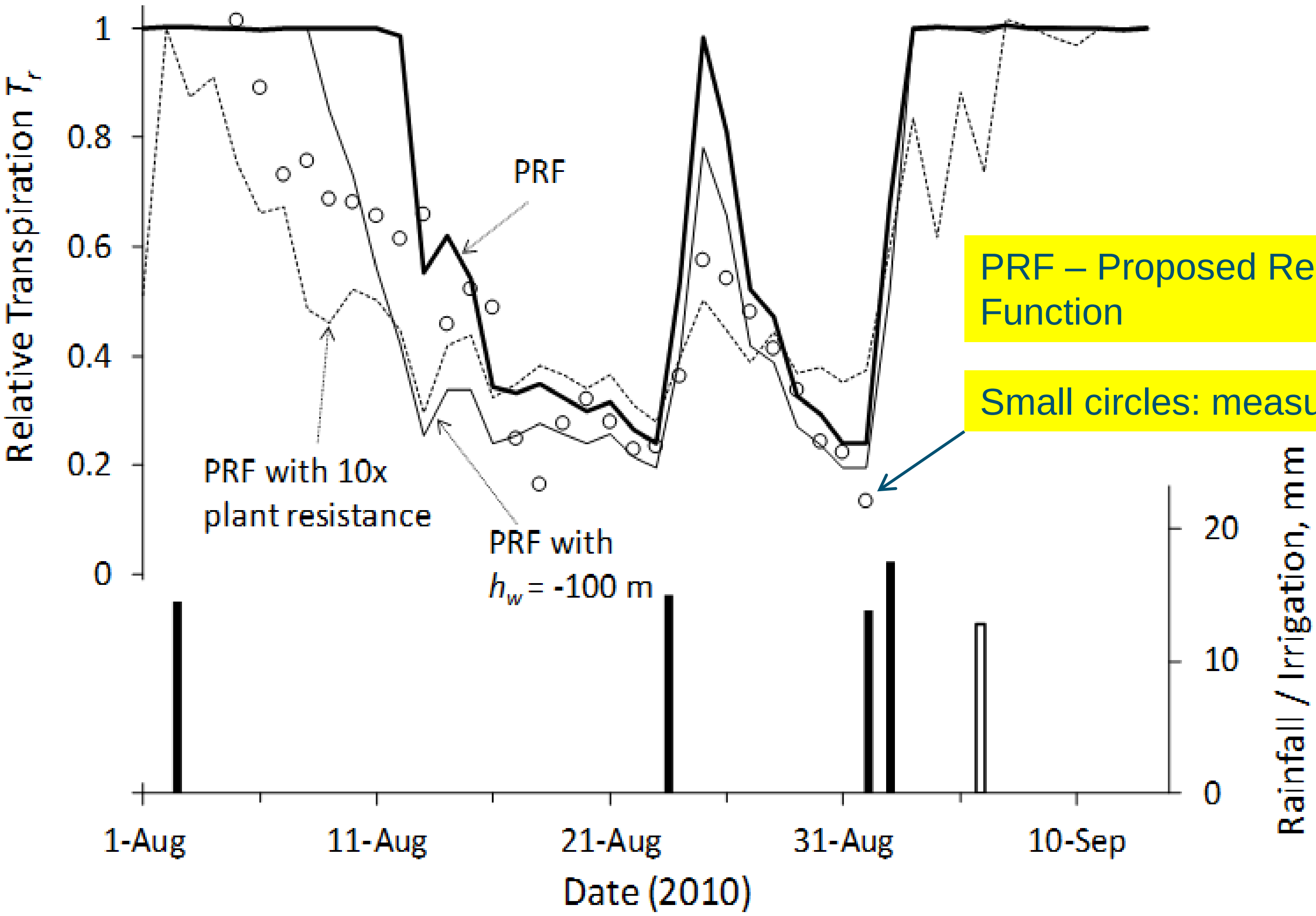
Simulated versus measured transpiration



PRF – Proposed Reduction Function

Small circles: measurements

Growth of common bean, Brasil

Next steps

- Verification with lysimeter and field measurements
- Derive empirical parameters of macroscopic models
- Include horizontal root density variation
- Include dynamic root density development

WaterWijzer Landbouw

Op dit moment in Nederland 3 methoden
voor schade door te nat of te droog:

- HELP tabellen
- TCGB tabellen
- Agricom

Actualisatie schadefuncties nodig:

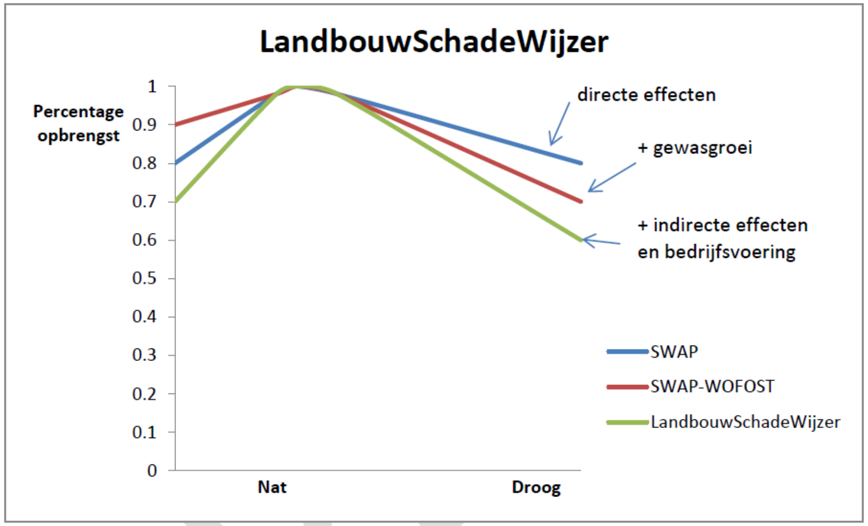
- Veel impliciete kennis opgenomen
- Resultaten niet reproduceerbaar
- Alleen langjarige gemiddelde schades
- Gebaseerd op verouderde weer- en gewasgegevens
- Geen zoutstress opgenomen

Einddoel project WaterWijzer (STOWA, 2013):
‘Een uniform en breed gedragen systeem voor het bepalen van
klimaatrobuuste relaties tussen waterhuishoudkundige condities en gewasopbrengsten’

WaterWijzer Landbouw (vervolg)

In opdracht van STOWA, samenwerking tussen:
- Alterra (penvoerder)
- KWR Watercycle
- Wageningen Universiteit
- Bakelse Stroom

Eerste fase (gereed):
- SWAP-WOFOST operationeel om klimaatrobuuste verdampingsreducties voor droogte, natheid en zout te simuleren



Tweede fase (oktober 2013 – maart 2015):
- Toetsing koppeling SWAP – WOFOST voor de gewassen gras, aardappel en snijmaïs voor berekening opbrengstreducties
- Afleiden metarelaties, gebaseerd op SWAP-WOFOST, voor diverse bodemtypen, meerdere klimaatscenarios en voor de gewassen gras, aardappel en snijmaïs
- Actualiseren kennis over indirecte schade (structuur, opkomst, oogst)
- Koppeling SWAP-WOFOST aan BBPR (BedrijfsBegrotingsProgramma Rundvee)