

Sperry's supply-demand-loss model

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1 Introduction

Sperry and Love (2015 (What plant hydraulics can tell us about responses to climate-change droughts)) developed a model where a supply function ($E_{p-canopy}$) is derived which calculates the potential rate/amount of water able to be supplied from the soil to the atmosphere, i.e. potential transpiration. Transpiration is influenced by xylem pressure (ψ_{xylem}), hydraulic conductivity of the plant (K_{plant}), the hydraulic conductivity of the soil K_{soil} and the rate at which hydraulic conductivity is reduced as xylem pressure increases or soil conductivity decreases.

Below are parameters for the vulnerability-conductance curve,

```
p50 <- 2.5 # the matric potential where conductance is reduced by 50%
K_max <- 8 # maximum plant conductance - this is a trait in aDGVM2
res <- 1/K_max # resistance is simply the inverse of conductance
psi_canopy <- seq(0.0, 5, length=1000)
predawn_soil_mat_pot <- seq(0,2, by=0.5) # initial plant matric potential = soil matric potential
cum_can_transport <- matrix(0,0,nrow=1000, ncol=5) # this is the supply function

## make transpiration demand -----
# Maximum stomatal conductance
Gmax <- 12563.1 # (Sperry 2016, 2130 kg h-1 m-2) NOTE should be (kg h-1 MPa-1 m-2) (12563.1 in Excel)
G <- rep(Gmax, length=5)
#VPD <- 0.5*0.001 # (Sperry 2016, leaf-to-air vapor pressure deficit 1 kPa) (0.001 converts to MPa)
VPD <- 1.5*0.001 # (Sperry 2016, leaf-to-air vapor pressure deficit 1 kPa) (0.001 converts to MPa)
# NOTE VPD conversion from kPa to MPa isn't documented in Sperry, I'm doing it as it makes sense and produces
# amounts of transpirational demand.
#evap_demand <- G*VPD

# need to define an Pcrit, i.e. a matric potential we choose where we decide conductance is effectively zero
# We use this to get Ecrit, i.e. maximum transpiration beyond which leads to runaway cavitation
P_crit <- 4 # MPa - this is arbitrary and could be a plant trait.
# In Sperry (2016) a P_crit cutoff is chosen (either very low conductance or
# shallow slope of a tangent to the transpiration curve)

# get maximum transpiration possible based on Pcrit and soil matric potential
E_crit <- rep(0, length=5) # maximum transpiration beyond which leads to runaway cavitation
evap_demand <- rep(0, length=5) # evaporative demand
```

with the the conductance vulnerability curve we use in aDGVM2, which is analagous to Sperry's curve, defined as:

```
sperry_cond <- function(psi_canopy) { ((1 - (1 / (1 + exp(3.0*(p50 - psi_canopy)))))) / res }
```

The transpiration rate is the integral of the vulnerability-conductance curve between any the soil (pre-dawn) matric potential and ($p - canopy$)(canopy sap pressure) and is calculated as follows:

```
for(j in 1:length(predawn_soil_mat_pot))
{
  for(i in 1:1000)
  {
    ffx <- integrate(sperry_cond, predawn_soil_mat_pot[j], psi_canopy[i] )
```

```

        cum_can_transport[i,j] <- pmax(0, ffx$value)
    }
}

```

Here we get the slope of the line which is tangent to the transpiration curve at any particular water potential. This slope is the conductance at this water potential.

```

cond_max_slope_sperry <- rep(0, length=5) # get the maximum slope of conductance given pre-dawn water potential
for(i in 1:length(predawn_soil_mat_pot))
{
    cond_max_slope_sperry[i] <- sperry_cond(predawn_soil_mat_pot[i])
    # for Sperry the maximum conductance is always the pre-dawn matrix potential/soil matrix potential
}

```

We calculate the maximum transpiration beyond which leads to runaway cavitation E_{crit} based on a matrix potential we choose where we decide conductance is effectively zero P_{crit} .

```

for(j in 1:5)
{
    ffx <- integrate(sperry_cond, predawn_soil_mat_pot[j], P_crit )
    E_crit[j] <- pmax(0, ffx$value)
    evap_demand[j] <- G[j]*VPD
    if(evap_demand[j] > E_crit[j]) evap_demand[j] <- E_crit[j] # demand can't be greater than maximum supply
}

```

We then calculate the matrix potential where evaporative demand is met

```

## quick and dirty method to find the psi where demand is met.
demand_met_at_sperry <- rep(0, length=5)
psi_demand_met_at_sperry <- rep(0, length=5)
demand_met_at_slope_sperry <- rep(0, length=5)
loss_function_sperry <- rep(0, length=5)
regulated_transpiration <- rep(0, length=5)
regulated_leaf_psi <- rep(0, length=5)

for(i in 1:5)
{
    # positions on transport curve where supply can meet demand
    # this throws a warning but returns the first number which is what I want
    demand_met_at_sperry[i] <- which(cum_can_transport[,i] >= evap_demand[i])
    # the matrix potential where demand is met
    psi_demand_met_at_sperry[i] <- psi_canopy[demand_met_at_sperry[i]]
    # slope of tangent to supply/conductance curve where demand is met
    demand_met_at_slope_sperry[i] <- sperry_cond(psi_demand_met_at_sperry[i])
    # this is sperrys loss function (slope where demand is met / max slope)
    loss_function_sperry[i] <- demand_met_at_slope_sperry[i] / cond_max_slope_sperry
    # this is the adjusted leaf matrix potential dP = dP' * (demand_met_at_slope_sperry / cond_max_slope_sperry)
    regulated_leaf_psi[i] <- predawn_soil_mat_pot[i] + ((psi_demand_met_at_sperry[i] - predawn_soil_mat_pot[i]) *
    # this is the adjusted leaf matrix potential dP = dP' * (demand_met_at_slope_sperry / cond_max_slope_sperry)
    # dP' = predawn_matrix_potential - unregulated_matrix_potential, this doesn't work unless dP is added to predawn_matrix_potential

    ffx <- integrate(sperry_cond, predawn_soil_mat_pot[i], regulated_leaf_psi[i] )
    regulated_transpiration[i] <- pmax(0, ffx$value) # regulated transpiration (E in Sperry)
    G[i] <- G[i]*loss_function_sperry[i] # regulated stomatal conductance
    # E = G * VPD so G = E/VPD
}

```

From Sperry (2016) "Mathematically, P rises to a maximum before decreasing back to zero as E increases to E_{crit} . This decline in P is unrealistic (Saliendra et al., 1995), so it is assumed that P saturates at its maximum

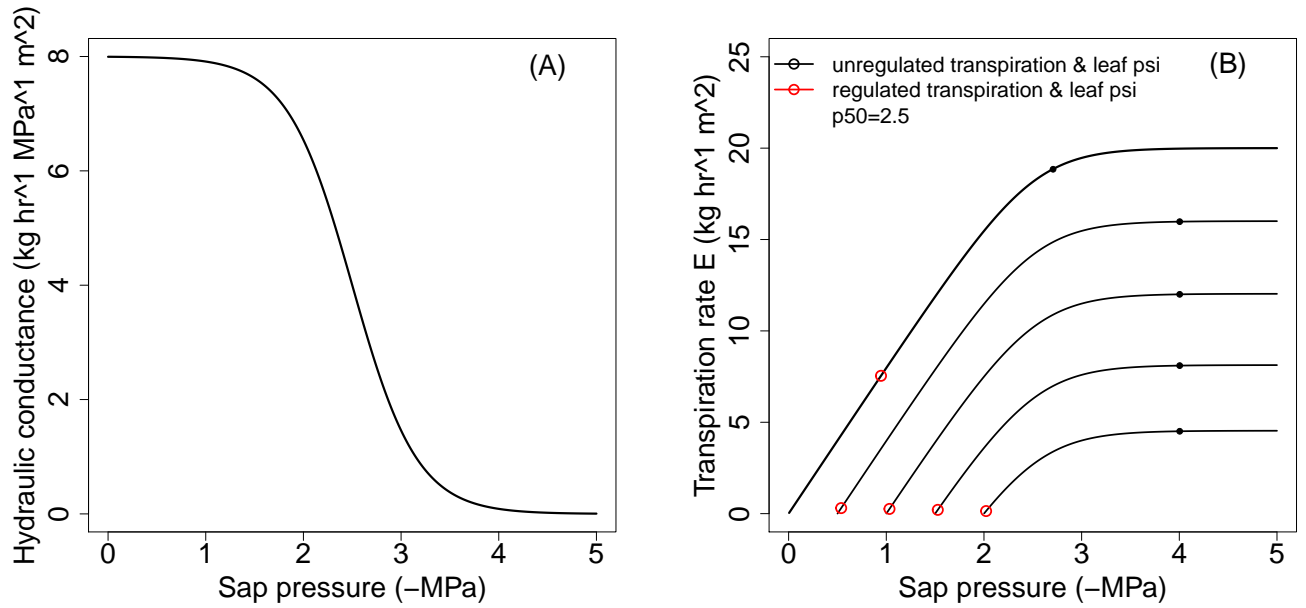


Figure 1: Hydraulic conductance and transpiration as a function of sap xylem pressure.

as E_0 increases. Eqn 5 expresses the outcome that xylem pressure is regulated in proportion to the damage caused by taking no action. (4) The regulated E corresponding to P is determined from the supply function. (5) The G is solved from E/D to determine how much it is reduced below G_{max} . The model does not partition G into stomatal vs boundary layer components, but G is controlled by stomatal regulation. Cuticular water loss is assumed to be zero." I was unsure what Sperry meant with ΔP saturates however examining Fig.1B one can see the regulated response is too extreme. Plotting the regulated leaf matrix potential against the demand defined matrix reveals that the regulated leaf matrix potential reaches a maximum and then decreases (Fig.2).

```
## Error in regulated_leaf_psi[, 1]: incorrect number of dimensions
## Error in text.default(4.5, 7.8, "(A)", cex = 2): plot.new has not been called yet
```