

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 sap pressure P , canopy sap pressure P_{canopy} , hydraulic conductance of the plant (k) ($\text{kg hr}^{-1} \text{MPa}^{-1} \text{m}^{-2}$), 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, 8, length=1000)
predawn_soil_mat_pot <- seq(0,3, length=5) # this assumes initial plant matric potential is the same as the soil
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 <- 0.5*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 <- 6 # 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)

##-----
##-----
## max regulation is the point where delta P hits its maximum, it should be held at max once passed.
G <- matrix(Gmax, Gmax, ,nrow=1000, ncol=5)

psi_1 <- matrix(0,0,nrow=1000, ncol=5)#
slope_demand <- matrix(0,0,nrow=1000, ncol=5)
loss_fun_sp_gs <- matrix(0,0,nrow=1000, ncol=5)
reg_leaf_psi <- matrix(0,0,nrow=1000, ncol=5)

regulated_trans <- matrix(0,0,nrow=1000, ncol=5)
regulated_Gs <- matrix(0,0,nrow=1000, ncol=5)

regulated_trans_trap <- matrix(0,0,nrow=1000, ncol=5)
regulated_Gs_trap <- matrix(0,0,nrow=1000, ncol=5)

non_regulated_trans <- matrix(0,0,nrow=1000, ncol=5)
non_regulated_Gs <- matrix(0,0,nrow=1000, ncol=5)

max_slo_sp <- rep(0, length=5)

for(j in 1:5)
{
  max_slo_sp[j] <- sperry_cond(predawn_soil_mat_pot[j])
}

```

```

}

for(j in 1:5)
{
  for(i in 1:1000)
  {
    psi_1[,j] <- seq(0, max(psi_canopy), length=1000) #psi_leaf[i]
    slope_demand[i,j] <- sperry_cond(psi_1[i,j])

    ffx <- integrate(sperry_cond, predawn_soil_mat_pot[j], psi_1[i,j] )
    non_regulated_trans[i,j] <- pmax(0, ffx$value)
    non_regulated_Gs[i,j] <- non_regulated_trans[i,j]/VPD # E = G*VPD ---- G = E/VPD (VPD=1, 0.001 transforms to MP)

    loss_fun_sp_gs[i,j] <- slope_demand[i,j] / max_slo_sp[j]
    #reg_leaf_psi[i,j] <- predawn_soil_mat_pot[j] + ((psi_1[i,j] - predawn_soil_mat_pot[j])*loss_fun_sp_gs[i,j])
    if(i==1) reg_leaf_psi[i,j] <- pmax(0, ((psi_1[i,j] - predawn_soil_mat_pot[j])*loss_fun_sp_gs[i,j]))

    if(i>1)
    {
      reg_leaf_psi[i,j] <- pmax(0, pmax(reg_leaf_psi[i-1,j], ((psi_1[i,j] - predawn_soil_mat_pot[j])*loss_fun_sp_gs[i,j])))
    }

    #
    ffx <- integrate(sperry_cond, predawn_soil_mat_pot[j], predawn_soil_mat_pot[j] + reg_leaf_psi[i,j] )
    regulated_trans[i,j] <- pmax(0, ffx$value)
    regulated_Gs[i,j] <- regulated_trans[i,j]/VPD # E = G*VPD ---- G = E/VPD (VPD=1, 0.001 transforms to MP)
    G[i,j] <- G[i,j]*loss_fun_sp_gs[i,j]

  }
}

demand_place_holder <- rep(0, length=5)
supply_limit_place_holder <- rep(0, length=5)
min_diff_place_holder <- rep(0, length=5)
supply_place_holder <- rep(0, length=5)

for(i in 1:5)
{
  a <-which(non_regulated_trans[,i] >= evap_demand[i])
  demand_place_holder[i] <-a[2]

  min_diff <- regulated_trans[,i] - non_regulated_trans[demand_place_holder[i]]
  min_diff_max <- which(min_diff == max(min_diff))
  supply_limit_place_holder[i] <- min_diff_max[1]

  abs_min_diff <- abs(min_diff)
  abs_min_diff <- which(abs_min_diff == min(abs_min_diff))
  supply_place_holder[i] <- abs_min_diff[1]
}

```

From Sperry (2016) "Mathematically, P rises to a maximum before decreasing back to zero as E_0 increases to E_{crit} . This decline in P is unrealistic (Saliendra et al., 1995), so it is assumed that P saturates at its maximum 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 ment with ΔP saturates however examining Fig.1B one can see the regulated response is too extreme. Plotting the regulated leaf matric potential against the demand defined matric reveals that the regulated leaf matric potential reaches a maximum and then decreases. Fixing the regulated leaf matric potential to its maximum

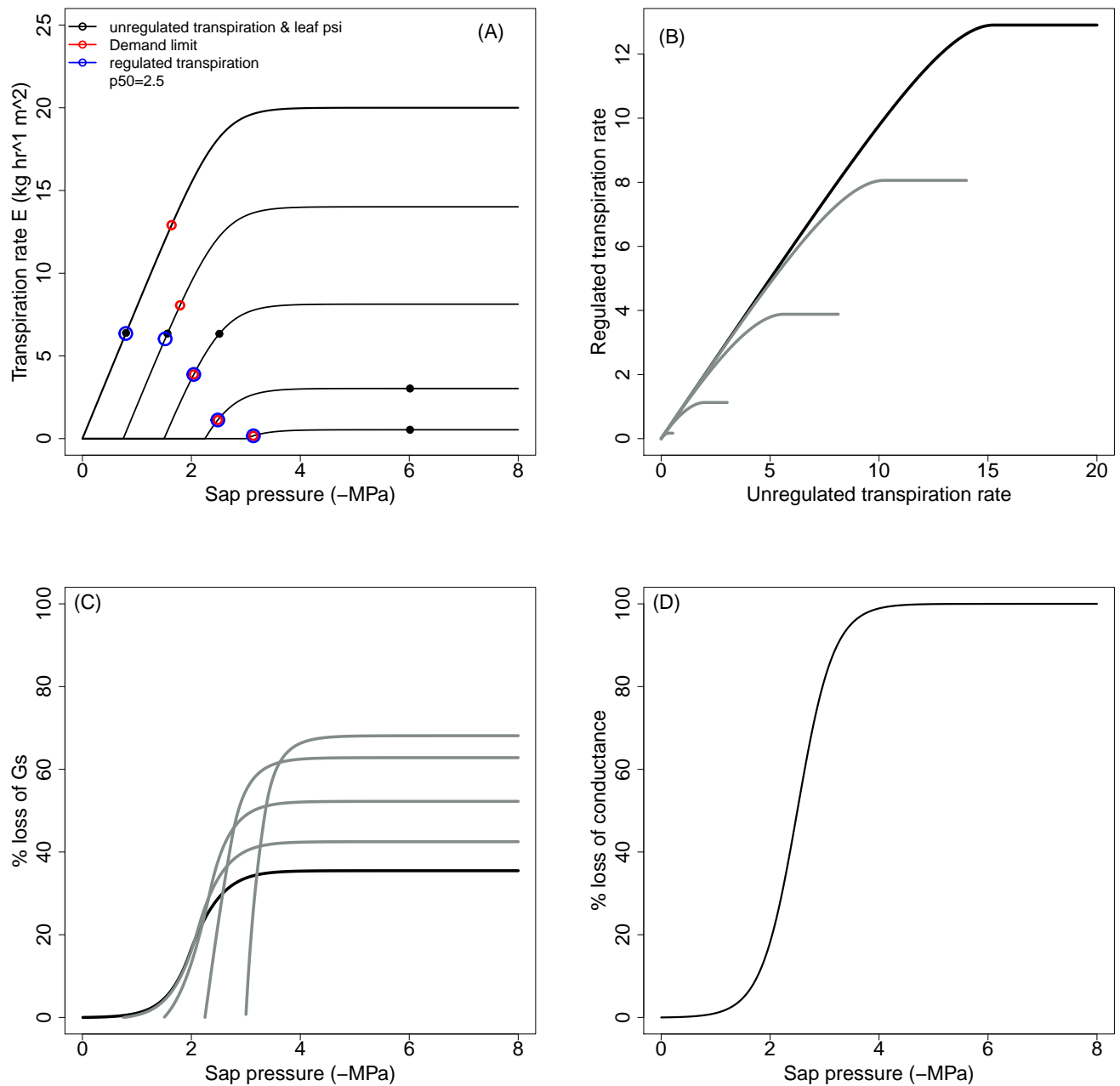


Figure 1: (A) Unregulated and regulated transpiration with supply demand limit. Where curves intersect the x-axis indicate the predawn/soil matrix potential. (B) Regulated vs unregulated transpiration. the differing curves represent the responses for the differing predawn/soil matrix potentials in (A). (C) Loss of stomatal conductance NOTE I haven't worked out how Sperry is producing his Fig.4 in Sperry and Love (2015). The differing curves correspond to the differing predawn/soil matrix potentials in (A). (D) percentage loss of conductance.

value once it has passed this value solves this issue. The next issue to solve is how sperry is calculating his percentage loss of stomatal conductance.