

FACETA: AN INDIVIDUAL-BASED MODEL FOR FOREST  
LANDSCAPE SIMULATION

USER's Guide v 1.0.0

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# 1 INTRODUCTION

FACETA is an individual-based model for landscape simulation. This document corresponds to version 1.0.0. FACETA is derived from ZELIG v FACET 2.4 which is a modification of the ZELIG model (Urban 1991,1993, Urban and Shugart 1992).

This manual documents the changes made to the code of ZELIG FACET 2.4 during the period 1995-2006, to adapt it to several conditions:

1. Capability to generate files to calibrate MOSAIC, a probabilistic semi-Markov landscape model documented in several papers (Ablan 1997, Acevedo et al, 1995a,b, 1996, 2001a,b, Urban et al. 1999).
2. Capability to impose a gradient of rainfall and soils independently from lapse rates and capability to select driving solar radiation from a model or from data (implemented for Delgado 2000)
3. Capability to correct ET calculations by adding an advection factor, hurricane effects and soil water logging (Abbott-Wood 2002).
4. Capability of species response to soil water logging for bottomland forests in the Trinity River (north Texas), Weir Woods (Big Thicket) and Caparo (Venezuela). A predecessor code using ZELIG (not FACET) was implemented for Holcomb 2001.

In addition to the output files produced by ZELIG, FACETA includes several new files and modifications to others. All input files now have extension \*.inp and all output files now have extension \*.out.

## Input files

- clima\*.inp climate data
- control\*.inp simulation control
- ent\*.inp terrain conditions
- spp\*.inp species parameters
- soil\*.inp soil parameters by soil type
- mos\*.inp forest types definition for mosaic

## Output files:

- watersoil.out soilwater tracer by row of first column of plots
- watersurf.out surface water tracer by row of first column of plots
- waterint.out soil water integration to obtain cm-day
- waterbalday.out daily balance by stand
- envtr.out Environmental factors tracer produced at the frequency controlled by ITRX in Control file
- barea.out tracer of basal area by species
- density.out tracer produced at frequency controlled by IDEN in Control file
- regrow.out regen and growth tarcr
- stand.out species composition and stems per diameter class
- total.out Total or aggregated stand variables, tracer file at frequency controlled by ITOT

- transplot.out transition by plot
- transtra.out transition summary
- debug.out debugging results

In this version of the manual we will concentrate in topic 4 above. Which has not been so reported in papers. The other topics (that have been reported in the several papers cited above) will be included in next editions of the manual.

## 2 SPECIES RESPONSE TO SOIL WATER LOGGING

ZELIG v FACET 2.4 included drought tolerance or species response to lack of soil water. There are some situations where the opposite situation is also of interest, that is species response to continuous soil saturation. For example: 1) at altitudes and aspects of frequent rainfall in mountainous terrain, such as it occurs in the higher elevations of the Luquillo Experimental Forest of Puerto Rico (Abbott-Wood, 2002). 2) at lower elevations in floodplains for bottomland and riparian forests (Holcomb, 2000). Some species are less tolerant than others to excess soil moisture or soil water logging. So in FACETA we have developed a new species response function in to account for these differences in tolerance to water stress factors. To build the response function it was necessary to develop an excess soil water-factor that was programmed in the soil water dynamics of FACETA.

This factor is based on the same logic of ZELIG V. FACET 2.4's drought factor, which is calculated as number of days when soil moisture is at wilting point divided by the total number of days in the growing season. Therefore for the species response to excess water in FACETA we have used a proportion of wet days during the growing season. These are defined as those days when soil water is at saturation. NOTE: The entire logic will be changed soon to work with an integrated water-availability index (soil water available to trees and seedlings integrated over the season).

### 2.1 FACETA soil water dynamics: additional water input according to terrain position

For the same amount of precipitation, soil moisture factors may vary across the landscape or study area because of the topographic position of the stand. For example, a stand located at low elevation and flat terrain may have more soil moisture than a stand located at higher elevations in steep terrain. Thus, an important factor is the amount of run-on flow received from other areas of the landscape. A prototype of this input parameter was implemented in ZELIG in an ad-hoc manner (Holcomb 2001).

To make these input conditions more realistic we incorporate these factors in FACETA using GIS data layers for the study area, defining the terrain. Input conditions are added to FACETA **ent** file in order to represent the rain water that runs onto a low-lying plot from surrounding areas. Another input condition related to storage capacity will be added as an input to FACETA to simulate the pooling of surface water and is not yet implemented.

An additional amount of water  $Q_{on}$  from upstream catchment is derived by

$$Q_{on} = r \times (C/100) \times Au \quad (1)$$

where  $r$  is rainfall,  $C$  is upstream runoff coefficient (i.e., an average percent of the rain that gets converted to run-off upstream from the FACETA stand),  $Au$  is the area of the upstream area or catchment's area that drain to the stand. See Figure 2-1.

For linkage to the Compound Topographic Index (CTI) concept to be explained later, we employ the concept of "specific" catchment area,  $Ac$ , which is the catchment area per unit of length of receiving cell (crosswise to direction of flow). We assume that

landscape information is provided by a raster or grid formatted GIS file, i.e., composed of a grid of square cells of equal size  $d \times d$ , and so the specific area is

$$Ac = A/d \quad (2)$$

See Figure 2-1. The catchment's area can be calculated by the product of  $Na$  the number of landscape cells in the upstream catchments that drain to this stand. This is an operation in GIS commonly referred to as flow accumulation and we will be discussed later. Then,

$$A = Na \times (d \times d) \quad (3)$$

and therefore

$$Ac = Na \times (d \times d) / d = Na \times d \quad (4)$$

Both  $C$  and  $Ac$  are new site input parameters to FACETA characterizing the terrain type of the stand. Therefore the area  $Au$  is the specific area  $Ac$  times the length of the stand, which in turn is the number of columns of plots multiplied by the width of a plot (which is the square root of  $Ap$ , the area of the plot

$$Au = Ac \times nc \times \sqrt{Ap} \quad (5)$$

The additional amount of water  $Q_{on}$  is added to the top row, or top of the flow path because as inherited from ZELIG v FACET 2.4 water flows down each columns of plots. Substituting  $Q_{on}$  from equation (1) and  $Au$  from equation (5) then divides  $Q_{on}$  into the number  $n_c$  of columns of the stand (FACETA grid)

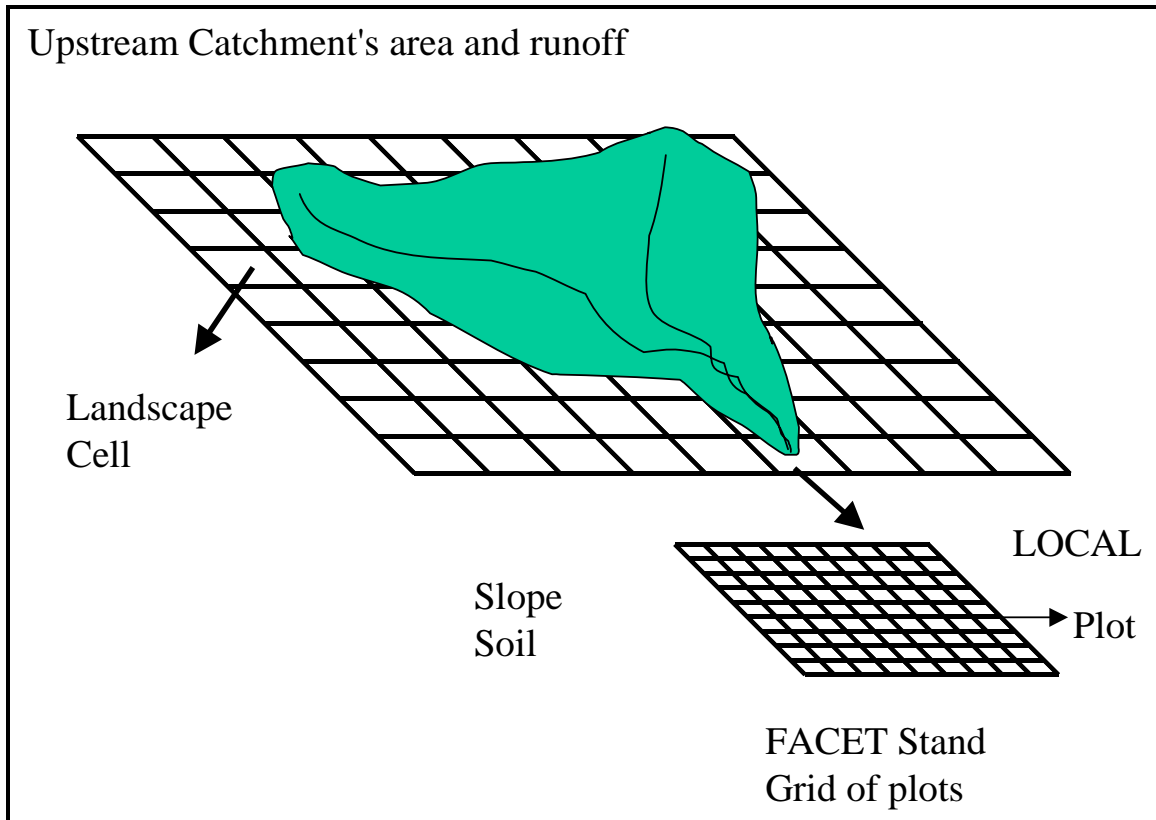
$$q_{on} = \frac{Q_{on}}{n_c} = \frac{r \times (C/100) \times Ac \times nc \times \sqrt{Ap}}{n_c} \quad (6)$$

and therefore

$$q_{on} = r \times (C/100) \times Ac \times \sqrt{Ap} \quad (7)$$

Therefore internally FACETA calculates  $q_{on}$  from equation (7) using inputs  $C$  and  $Ac$  and and this amount is an increased water input to each plot of the top row

$$q_{plot} = r + q_{on} \quad (8)$$



**Figure 2-1 Local and catchment**

The user is responsible for calculation of  $A_c$  and  $C$ . Example: Suppose that we have  $N_a=100$  cells from a DEM of  $30 \times 30$  m cells, that is  $d=30$  m. In this case following equation (3)

$$A_c = 100 \times 30 = 3,000 \text{ m}^2$$

For illustration, assume the FACETA grid has  $A_p=400$  m<sup>2</sup> of plot size, and that the average runoff coefficient upstream is  $C=3\%$  we get for a rain  $r=1$  mm the following runoff

$$q_{on} = 1 \times 3 / 100 \times 3,000 \times \sqrt{400} = 1800 \text{ mm}$$

then we get an additional water input to the each plot in the top row of 1800 mm. The last calculation is done internally in FACETA. This water can infiltrate or runoff to next plot according to slope and wetness. This is accomplished with a new runoff function in the code and discussed later.

The terrain conditions  $A_c$  and  $C$  are input to FACETA as terrain type parameters in the **ent** file. This file permits executing FACETA without responding to the prompts on the screen as in ZELIG v FACET. Information from the file gets piped as if coming from the keyboard. For example to input  $A=90000$  and  $C=3\%$ .

**Table 1 Example of input ent file**

Control	Name of control file
sitegbc.txt	name of site input file
sppgbc.txt	name of species input file

mosgbc.txt	Name of mosaic input file
200	Elevation in m
0.5	Slope in %
90	Aspect in deg
1	Soil type
3000	Specific Area of catchment in m <sup>2</sup> /m
3	runoff Coefficient (in %)
1	Disturbance damage class (not used for gbc)
1	Switch for seed of random number generation
0	Switch for no calibration

## 2.2 Landscape calculation of additional water

The additional water as run-on from upstream is determined through a series of GIS steps that start with the digital elevation model (DEM) layer and supported by the compound topographic index (CTI), as proposed by Goetz (2004). The CTI is also referred to as the steady state wetness index and is used in other simulation models (e.g., TOPMODEL). It should be pointed out that the CTI is used to prepare input for FACETA runs and is not intended to be part of the dynamic calculations of soil moisture.

The Compound Topographic Index (CTI) is a measure of the tendency of water to accumulate in any cell, and the tendency for the force of gravity to move that water out of that cell. The CTI map is obtained from the flow accumulation and slope maps, which are both generated from the DEM. The slope is calculated directly from the DEM, while flow accumulation is derived from slope and aspect. The flow accumulation map represents, for each cell, the number of cells in the DEM layer that contribute run-on to that cell. We denoted this as  $N_a$  in the previous section.

The CTI employs the concept of “specific” catchment area  $A_c$ , defined in the previous section. The specific area is the catchment area per unit of length of receiving cell.  $A_c$  is calculated from the flow accumulation as indicated in equations (2) or (4). The CTI is then defined for each cell based on the specific catchment area and slope of that cell.

The catchments size or area is employed in the calculation of the CTI

$$CTI = \ln(A_c / \tan(\beta)) = \ln\left(\frac{A_c}{s/100}\right) \quad (9)$$

where  $\beta$  is the slope angle and  $s$  is the slope in percent. The slope in % and the  $A_c$  are given as an input to FACETA in the **ent** file. See Table 1. The CTI increases with catchment area and decreases with slope.

For example, for the values of  $A_c=3,000$  and  $s=0.5\%$  given above in Table 1, the CTI is

$$CTI = \ln\left(\frac{3000}{3/100}\right) = 11.51$$

Note that decreasing the slope increments the CTI. For example for  $s=0.1$

$$CTI = \ln\left(\frac{3000}{0.1/100}\right) = 14.91$$

Also that in upland areas with small  $A_c$  and higher slopes we decrement the CTI. For example for  $N_a=2$ , and  $s=3\%$

$$CTI = \ln\left(\frac{2 \times 30}{3/100}\right) = 7.60$$

The upstream runoff coefficient characterizes the terrain type in terms of much water can runoff from the catchment, which is function of land cover, soil and antecedent moisture conditions of the catchment. In this version we assume an average runoff coefficient upstream. To expand the CTI concept we can add the runoff coefficient  $C$ , which depends on land cover and land use to obtain a CTLUI

$$CTI_{LU} = \ln(C \times A_c / \tan(\beta))$$

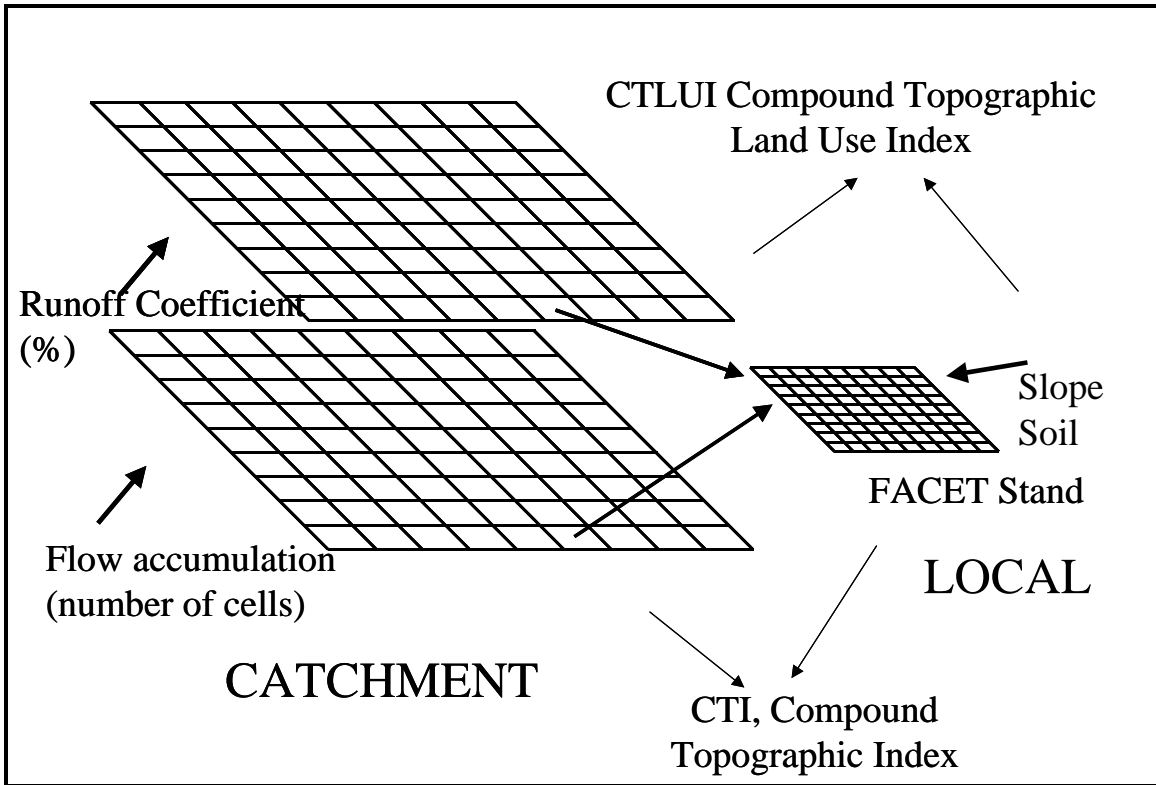
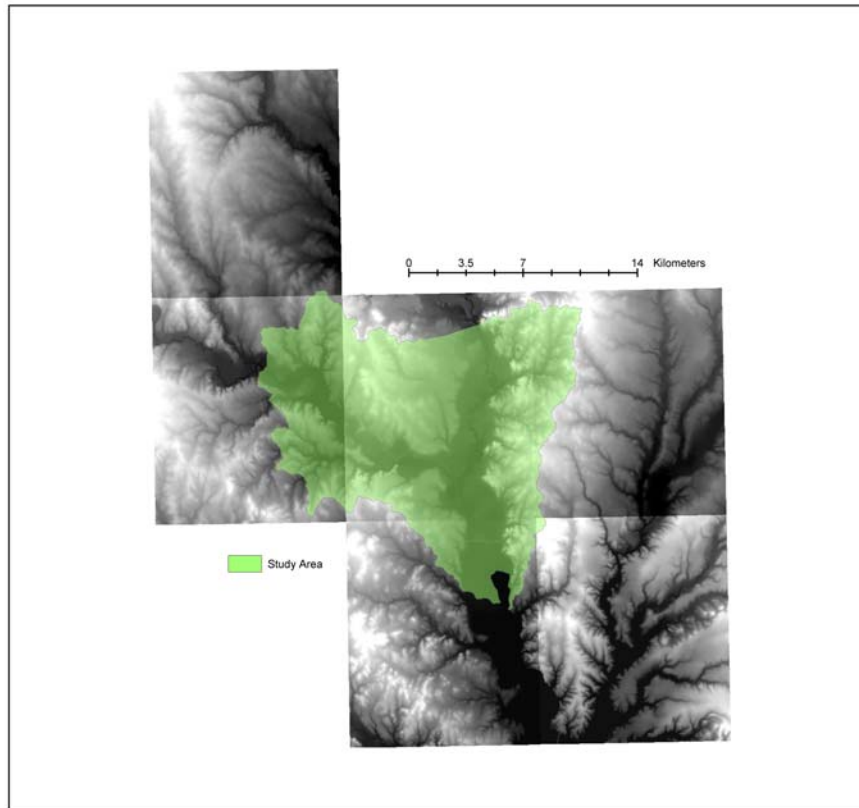


Figure 2-2 Terrain type: local and catchment



**Figure 2-3 Example of digital elevation model (DEM). Greenbelt Corridor of the Trinity River study area. Hydrological calculations start with the DEM.**

The CTI can be combined with soil type, land cover and land use to define the terrain types in the study area as proposed by Goetz (2004). All possible combinations of terrain type and forest cover type can then be input into FACETA for multiple runs. Results from the FACETA runs can be analyzed using the semi-Markov model parameter estimation program, SEMAPAR (Acevedo *et al.* 2001*a, b*). It should be pointed out that the CTI is used to prepare FACETA runs and is not intended to be part of the dynamic calculations of soil moisture.

### 2.3 Examples

The following R script can help calculation of CTI and prepare input for FACETA

```
#calculate CTI
d <- 30 # cell side

# define function
cti <- function(Na,sp) {
# Na number of cells flow accum
# sp slope in percent
  s <- sp/100
  Ac <- Na*d
```

```

CTI <- log(Ac/s)
result <- list(Ac=Ac,CTI=CTI)
return(result)
}

> # examples

> #Imataca Loma Na <- 1; sp <- 15
> loma <- cti(1,15); loma
$Ac
[1] 30

$CTI
[1] 5.298317

> # examples
> #Imataca valle Na <- 900; sp <- 0.01
> valle <- cti(900,0.01); valle
$Ac
[1] 27000

$CTI
[1] 19.41393

>

```

Shown here is an example for Imataca. The hills (“lomas”) with CTI=5.30 and valleys (“valles”) with CTI=19.41. Input for FACETA will be Ac=30, s=15 for loma and Ac=27000, s=0.01 for valle. For the sake of illustration here we also enter C=0.1% for both loma and valle.

## 2.4 FACETA surface and soil water dynamics

Weather (air temperature and precipitation) is generated in ZELIG V. FACET 2.4 on a monthly basis. Soil water dynamics is done at higher frequency by dividing each month into *nts* intervals. In FACETA we have set this *nts* as the number of days of each month, this means that the simulation time step for soil water is one day. The precipitation amount of the month is divided by the number of days of the month to obtain the mean daily rainfall. FACETA includes a daily rainfall simulator based on a Markov process of dry and rainy days.

### 2.4.1 Rainfall simulation

#### 2.4.1.1 Determining days with rain

A Markov model consists of a transition probability matrix  $\mathbf{P}$  that projects a vector of probabilities  $\mathbf{X}(t)$  through time. Each entry  $x_j(t)$  of this vector is the probability of being in state  $i$  at time  $t$ . Each entry  $p_{ij}$  of the matrix is a conditional probability of going to a state  $i$  at time  $t+1$  given that it was in state  $j$ . The entries of  $\mathbf{P}$  are conditional probabilities of transition from state to state.

$$\mathbf{X}(t+1) = \mathbf{P}\mathbf{X}(t) \quad (10)$$

Define two states for a day, state 1=dry day (it does not rain) or state 2 = wet day (it rains). Each day, the system can be in dry or wet state.

$$\mathbf{X} = \begin{bmatrix} X_1 \\ X_2 \end{bmatrix} \quad (11)$$

the probabilities  $X_1$  and  $X_2$  add up to 1 since the system can only be in one of these states then  $\mathbf{P}$  is  $2 \times 2$

$$\mathbf{P} = \begin{pmatrix} p_{11} & p_{12} \\ p_{21} & p_{22} \end{pmatrix} \quad (12)$$

an entry  $p_{ij}$  is the probability of transitioning from  $j$  to  $i$ . IN FACETA currently the matrix is specified by parameters for conditional probabilities  $p_{22} = P(\text{rain}|\text{rain})$  and  $p_{21} = P(\text{rain}|\text{dry})$ . Probabilities  $p_{11}$  and  $p_{21}$  have to add to 1 since the system has to transition somewhere from source state, state 1 in this case. Likewise for  $p_{12}$  and  $p_{22}$ , they have to add to 1. Then

$$\begin{aligned} p_{12} &= 1 - p_{22} \\ p_{11} &= 1 - p_{21} \end{aligned} \quad (13)$$

The stable distribution tells the probability that the system will be one of the states after a long-term run can be calculated from (10) by making  $X(t+1) = X(t) = X^*$  to obtain

$$\mathbf{X}^* = \mathbf{P}\mathbf{X}^* \quad (14)$$

or

$$(\mathbf{P} - \mathbf{I})\mathbf{X}^* = 0 \quad (15)$$

and then we need to solve for  $\mathbf{X}^*$

$$\begin{bmatrix} X^*1 \\ X^*2 \end{bmatrix} = \begin{bmatrix} 1 - p_{21} & p_{12} \\ p_{21} & 1 - p_{12} \end{bmatrix} \begin{bmatrix} X^*1 \\ X^*2 \end{bmatrix} \quad (16)$$

also

$$X^*2 = 1 - X^*1$$

therefore

$$X^*1(1 - p_{21}) + p_{12}(1 - X^*1) = X^*1 \quad (17)$$

and solving for  $X^*1$

$$X^*1 = \frac{p_{12}}{p_{21} + p_{12}} \quad (18)$$

therefore  $X^*2$  is just  $1 - X^*1$

$$X^*2 = \frac{p_{21}}{p_{12} + p_{21}} \quad (19)$$

which can be rewritten using the parameters specified in FACETA by using equation (13)

$$X^*2 = \frac{p21}{1 - p22 + p21} \quad (20)$$

An often used method to generate daily rainfall consists of two steps: first determine occurrence of rain in a day, this is to say whether a day is wet or rainy (say when precipitation exceeds 0.2 mm) then the precipitation amount for that day is generated according to a distribution skewed such to reflect the fact that daily rainfall frequency has higher values towards the low values of rainfall, i.e, it is more common to have low rainfall values than high or extreme values.

As an example consider

$$\mathbf{P} = \begin{bmatrix} 0.4 & 0.2 \\ 0.6 & 0.8 \end{bmatrix} \quad (21)$$

Note that entry p21 is Prob(wet|dry) and p12 is Prob(dry|wet). Here the bar denotes conditioning the probability. Also p21=1-p11 and p12=1-p22

Let's calculate the stationary distribution,

$$X^*1 = \frac{0.2}{0.2 + 0.6} = 2/8 = 1/4 = 0.25 \quad (22)$$

and  $X^*2 = 3/4 = 0.75$ .

On the long run, the probability of a day being dry is 1/4 and of being wet is 3/4. As a long-term average, in a region there are about 50% percent of rainy days in a year, and 20% of the dry days are followed by rainy days. How often are dry days followed by dry days?. Then 50% percent of rainy days in a year means that  $X^*2 = 0.5$  whereas 20% of the dry days are followed by rainy days means that p21=0.2. Using equation (19) we obtain

$$p^*2 = \frac{p21}{p21 + p12} = \frac{0.2}{0.2 + p12} = 0.5$$

rearrange and then solve for p12 from  $p12 + 0.2 = 2 \times 0.2$  to get p12=0.2, then p11=1-p12=0.8. The answer is that 80% of the time dry days are followed by dry days.

#### 2.4.1.2 Determining rain amount

The Markov model is combined with the frequency distribution of rainfall in rainy days to determine the amount of rain, once a day is selected as wet or dry. Data from the site can be used to determine the distribution of rainfall for wet days and then use that distribution to draw samples. This is typically done for each month of the year.

Daily rainfall distribution is skewed towards the low values. The distribution parameters, e.g., mean and standard deviation, are varied month to month according to climatic records (weather statistics).

Currently in FACETA a gamma pdf is employed to model the rainfall amount

$$p(x) = \frac{(x/\beta)^{a-1} \exp(-x/\beta)}{\beta \Gamma(a)} \quad (23)$$

where the parameters  $a$  and  $\beta$  are **shape** and **scale** respectively. The **rate**  $b$  is the inverse of the scale, this is  $b=1/\beta$ . The mean and variance are

$$\mu_x = a\beta = a/b \quad \sigma_x^2 = a\beta^2 = a/b^2 \quad (24)$$

To generate rainfall with a given mean and variance of rain since we can solve for  $a$  and  $b$  from (24). Note that rewriting (24)

$$a = \mu_x b \quad \text{and} \quad a = \sigma_x^2 b^2 \quad (25)$$

and therefore

$$b\mu_x = b^2\sigma_x^2 \quad (26)$$

and therefore

$$b = \mu_x / \sigma_x^2 \quad (27)$$

using this to calculate  $a$  from (25)

$$a = \mu_x^2 / \sigma_x^2 \quad (28)$$

There is no closed form equation for the CDF unless the shape parameter  $a$  is an integer and in this case  $\Gamma(a) = (a-1)!$  and the PDF becomes the Erlang PDF

$$p(x) = \frac{(bx)^{a-1} \exp(-bx)}{(a-1)!}$$

$$F(x) = 1 - \exp(-bx) \sum_0^{a-1} \frac{(bx)^a}{a!}$$

Therefore, the inverse method for random generation can only be used when shape is integer using  $a$  as U(0,1) variates  $u_i, i=1, \dots, a$

$$x = -(1/b) \ln \left( \prod_{i=1}^a u_i \right)$$

The total rainfall in a month would be the sum of the rainfall amounts for the wet days, which is a random variable  $R$  combination of the number of wet days in the month (that occurs at random according to the Markov chain model) and the amount on wet days, occurring according to the distribution selected. The expected number of wet days is  $nX^*2$  where  $n$  is the total number of days in the month and  $X^*2$  is the probability of getting a wet day and given by equation (19). Therefore the expected rainfall for a wet day is the expected total for the month divided by the expected number of wet days

$$\mu_x = \frac{\mu_R}{nX^*2}$$

For example when using a gamma using the expression for the mean from (24)

$$\mu_R = nX^*2 a/b \quad (29)$$

The variance of  $R$  can also be calculated. For example, when  $X$  is a gamma

$$\sigma_R^2 = nX^*2 \sigma_x^2 \left( 1 + aX^*1 \frac{p22 + p11}{p21 + p12} \right) \quad (30)$$

As a numeric example, take a month with  $n=30$  days and with transition matrix given in equation (21) for which we calculated  $X^*2=3/4=0.75$ . For a gamma with  $a=0.8$ ,  $b=0.16$  using (24) we calculate the mean

$$\mu_x = a/b = 0.8/0.16 = 5$$

and therefore the mean daily rainfall is  $0.75 \times 5 = 3.75$  mm and the mean monthly rainfall for a month of 30 days is

$$\mu_R = 30 \times 0.75 \times 5 = 112.5 \text{ mm}$$

The variance of daily rainfall is

$$\sigma_x^2 = a/b^2 = 0.8/(0.16)^2 = 31.25$$

and the variance of monthly rainfall is calculated using equation (30)

$$\sigma_R^2 = 30 \times 0.75 \times 31.25 \times \left( 1 + 0.8 \times 0.25 \frac{0.4 + 0.8}{0.6 + 0.2} \right) = 914.06$$

In FACETA input is mean and standard deviation of each month. Scale and shape parameter values are calculated for each month.

## 2.4.2 Surface water dynamics

### 2.4.2.1 Surface Ponding

The additional **run-on**  $q_{on}$  calculated from equation (6) is added to the water rainfall to obtain water input to the plot  $q_{in}$ . A storage capacity (**pond height**), calculated from the slope, and a maximum pond level at the last row (**berm height**), is used to prevent all of the remaining water from running off once the soil has reached saturation. If the plot has a non-zero storage coefficient, then some portion of that water will remain on the plot, keeping the soil saturated. This is implemented using a berm height parameter  $h_b$  input by the user in the ent file. When  $h_b = 0$  then all water will runoff.

For each day  $t$  the pond height  $h_p(t)$  is measured with respect to the bottom elevation (or elevation of the cells in the last row). The pond line  $x_p$  from the bottom cell is calculated using the slope  $s$  is slope

$$x_p(t) = h_p(t) / s$$

The total length of the grid is

$$L = nr \times d$$

where  $nr$  is the number of rows, and  $d$  is cell size as above. The change of pond height  $dhp$  is calculated from the current pond height according to the following conditions. If the slope is zero, then simply  $dhp=q_{in}$ . If the slope is nonzero, then there are two conditions, if  $x_p > L$  then  $dhp=q_{in}$  as well. However, if  $x_p < L$  then we can first calculate the change in pondline by solving

$$dx_p^2 + 2x_p(t)dx_p - 2q_{in}L/s = 0$$

to obtain

$$dh_p = \sqrt{h_p^2 + sq_{in}L} - h_p \quad (31)$$

as before, nr is the number of rows, and d is cell size as above.

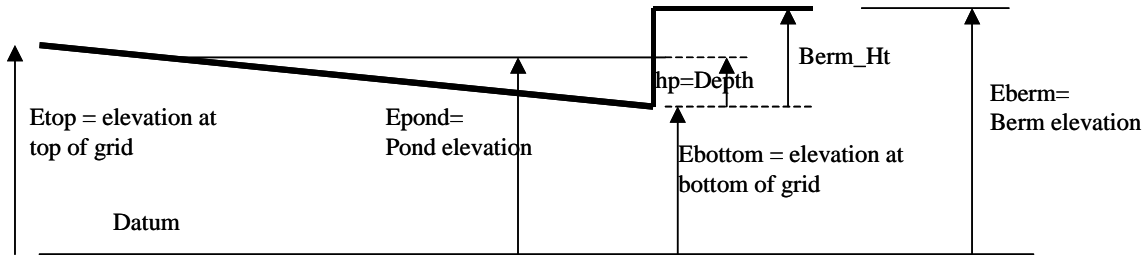


Figure 2-4 Ponding at the surface

Now if  $h_p$  calculated from equation (31) exceeds the berm height  $h_b$ , then the pond height is simply the maximum, which is the berm height  $h_b$ . See Figure 2-4. Once the pond reaches the berm height, it drains at an outflow rate  $q_d$  that changes with the pond height

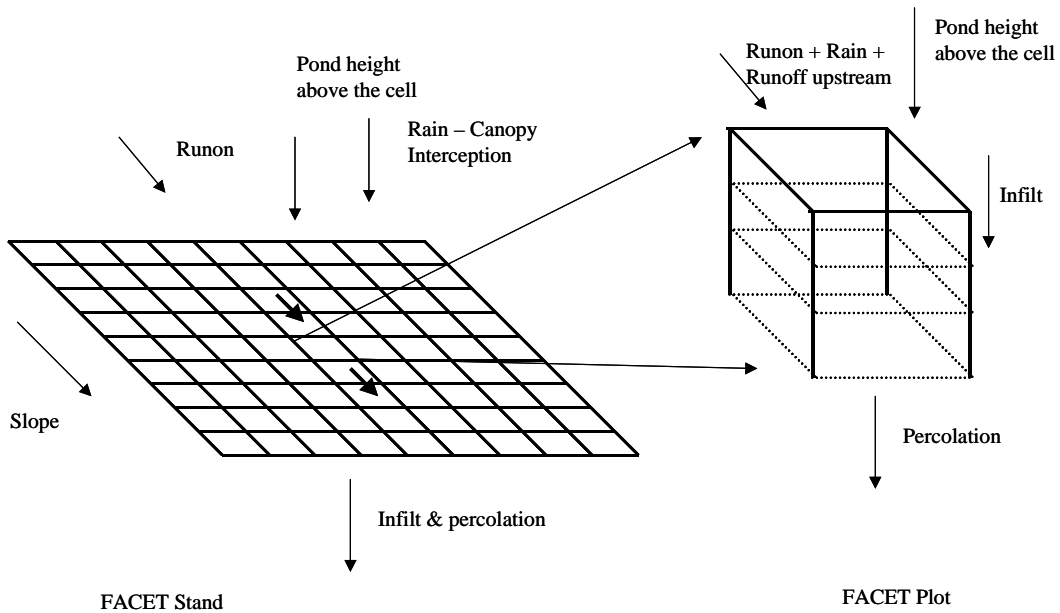
$$\begin{aligned} \text{if } (h_p(t) \geq h_b) \quad q_d(t) &= \gamma (h_p(t) - h_b)^\alpha \\ \text{else} \quad q_d(t) &= 0 \end{aligned} \quad (32)$$

by an **outflow coefficient**  $\gamma$  given by the user in file ent. Currently the power  $\alpha$  is set at 1 and therefore the coefficient  $\gamma$  has units of  $d^{-1}$  so that  $q_d$  has units of  $cm/d$  when  $h_p$  is given in  $cm$ . The coefficient  $\gamma$  represents the fraction of the pond height that drains per day.

For example in Caparo for terrain positions of banco, subbanco, bajio, we have used coefficient  $\gamma$  set at 1.0, 0.8, 0.7 respectively.

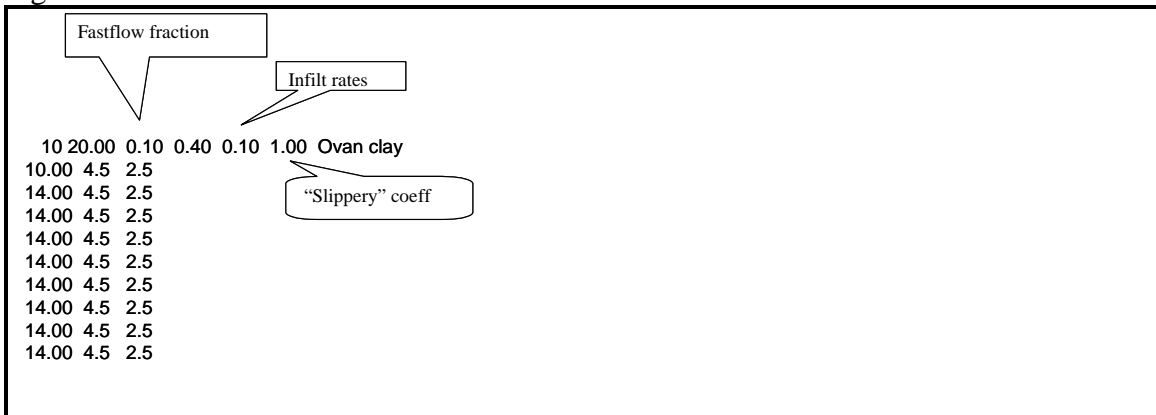
#### 2.4.2.2 Infiltration and runoff

For each plot, water available to infiltrate the soil is given by the rainfall (minus canopy interception) plus the pond height above the cell (which depends on cell elevation) or runoff from the upstream cell (if there is no pond). The total water available for infiltration (water input availability) is allowed to infiltrate into the soil at a rate that depends on soil type and percent of saturation. The infiltration rate is accomplished with a new runoff function in the existing routine of the ZELIG V. FACET 2.4 code. Once the soil is saturated, the remaining water can add to the pond or run off and become run-on for the plot downstream. The process is repeated until the water runoff the plot in the last row, becoming total runoff from the column, or accumulates on the pond. See Figure 2-5.



**Figure 2-5 Infiltration and percolation**

Soil water dynamics is interpolated in ZELIG V. FACET 2.4 from the monthly values by dividing each month into *nts* intervals. Soil water is tracked by layer with variable *swi* for the *ith* layer. The new infiltration rate in FACETA uses two new soil parameters: dry infiltration rate *I<sub>d</sub>* and wet infiltration rate *I<sub>w</sub>*. They are read from the site input file as *I<sub>d</sub>* and *I<sub>w</sub>* and given in cm/hr. These are input after fast flow fraction. See Figure 2-6.



**Figure 2-6 Infiltration rates are added to the soil parameters**

These infiltration rates are derived from infiltrometer experiments. The typical time course of infiltration follows a curve like shown in

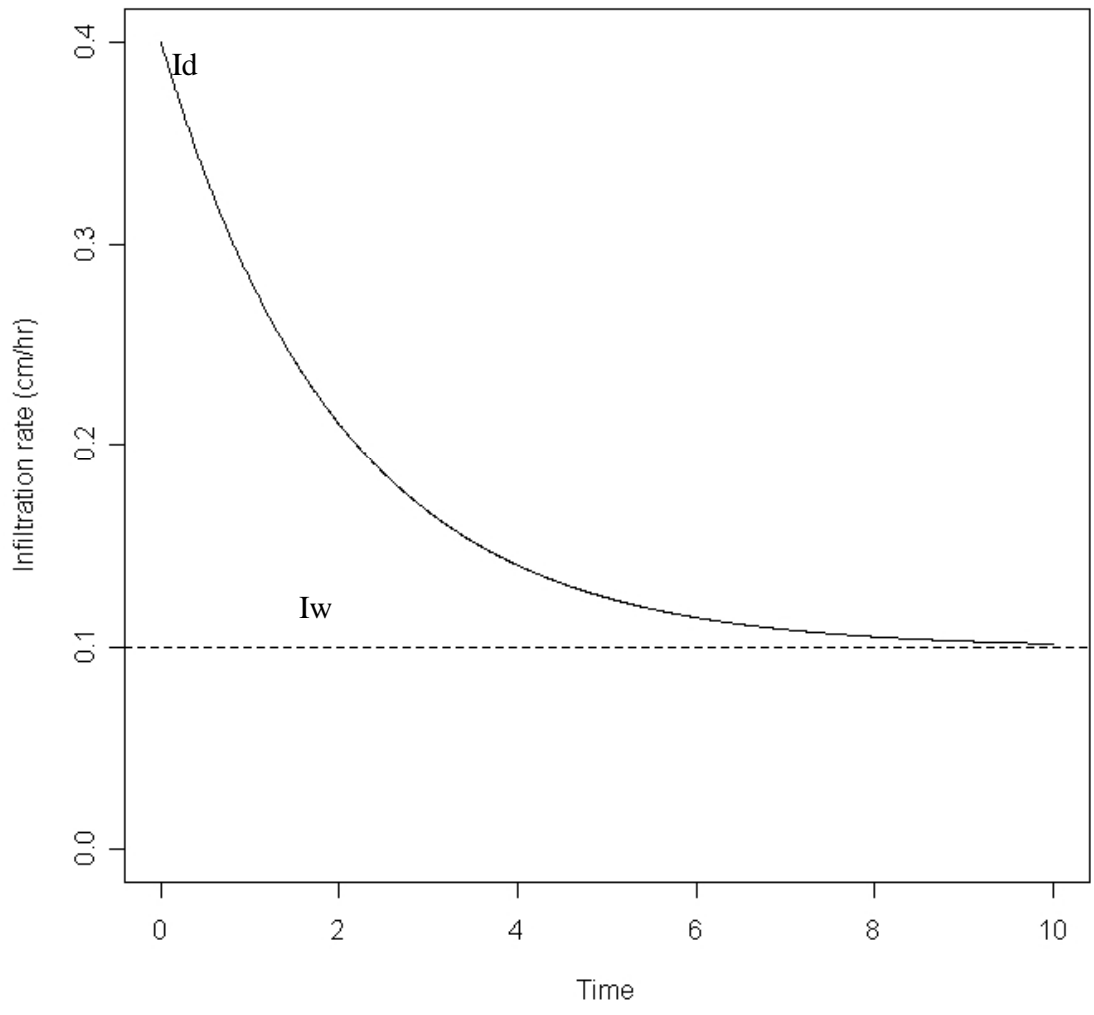
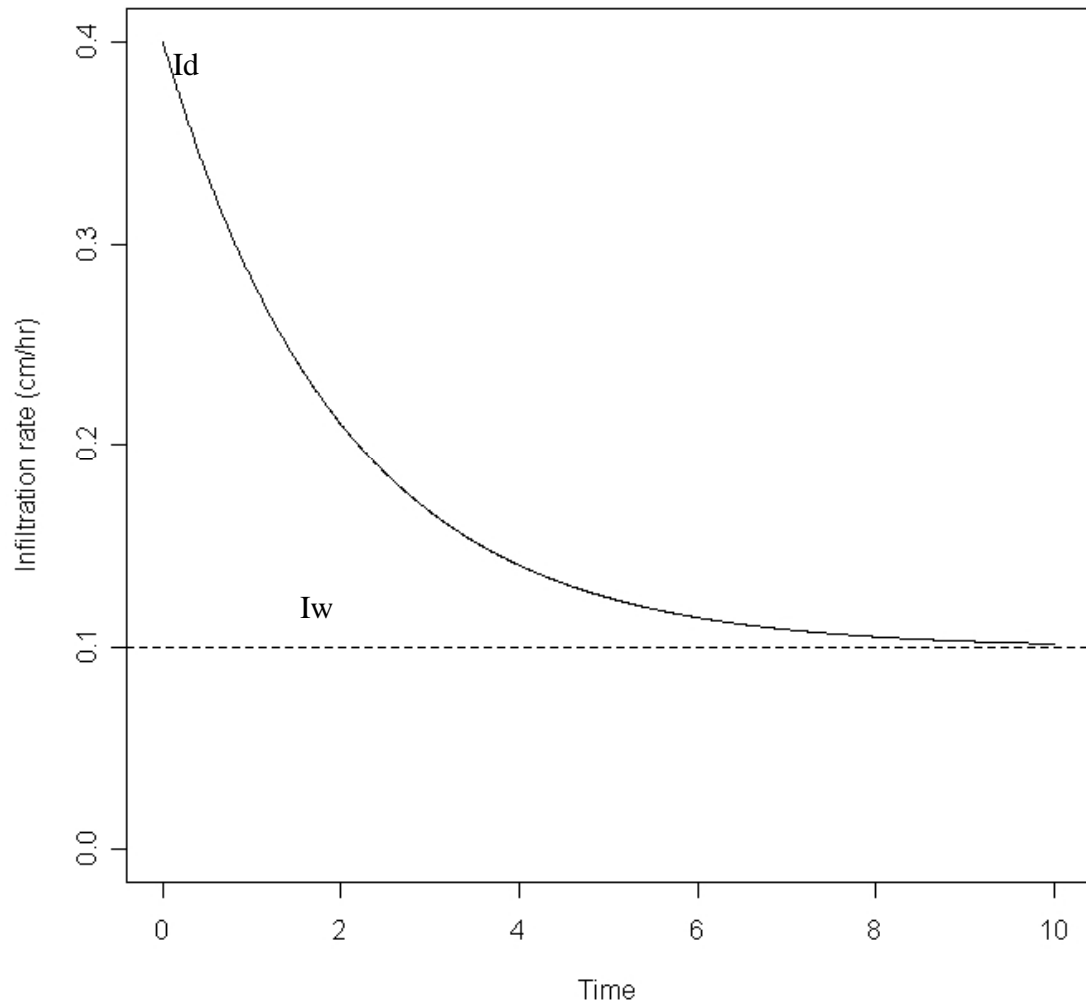


Figure 2-7



**Figure 2-7 Time course of infiltration rate from dry to saturation.**

In the code  $I_d, I_w$  are converted to the units of soil water dynamics in ZELIG V. FACET 2.4 multiplying by 24 and by 30/nts

$$I_d = I_{di} \times 24 \times 30 / nts \quad (33)$$

$$I_w = I_{wi} \times 24 \times 30 / nts \quad (34)$$

Actual infiltration rate is decided based on deficit. The deficit in each layer is calculated as the difference between field capacity and water content.

$$dw_i = fc_i - sw_i \quad (35)$$

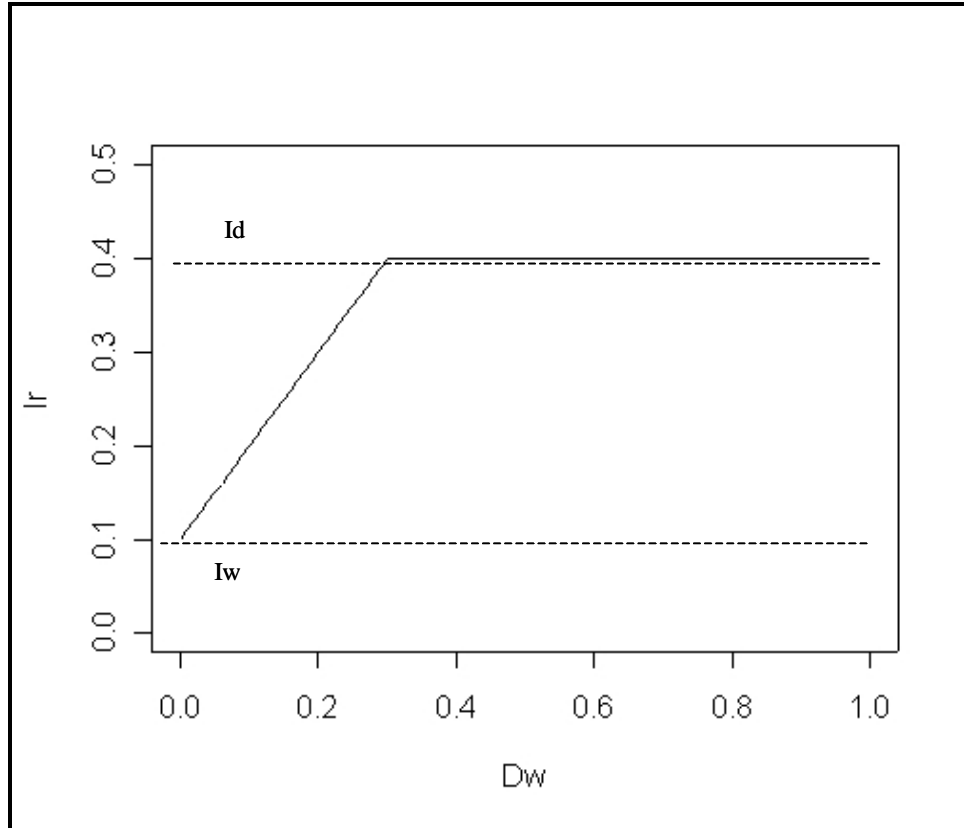
The total soil column deficit is calculated by adding all the deficits

$$Dw = \sum_i dw_i \quad (36)$$

If the deficit is zero  $D_w=0$  then all soil layers are at field capacity and the infiltration is set equal to the saturation or wet infiltration rate  $I=I_w$ . For non-zero deficit  $D_w >0$  then the infiltration rate achieves the maximum given by the dry infiltration rate  $I_d$  when the deficit plus the  $I_w$  exceed the  $I_d$  otherwise infiltration rate increases with the deficit

$$\begin{aligned}
 I &= D_w + I_w \text{ if } (D_w + I_w) < I_d \\
 &= I_d \text{ otherwise}
 \end{aligned}
 \tag{37}$$

This is illustrated in Figure 2-8.



**Figure 2-8 Infiltration rate as a function of soil water**

Next actual infiltration is affected by slope to account for gravitational forces. It is multiplied by a factor in between 0 and 1. That takes value 1 when the slope is 0% and 0 when the slope is 100%.

$$f_s = (1 - \beta / 100)^\alpha
 \tag{38}$$

where  $\alpha$  is a “slippery” coefficient made equal to 1 for now. It could give a shape factor to this decrease of infiltration with slope. When  $\alpha \gg 1$  the infiltration decreases rapidly for low values of slope; When this  $\alpha \ll 1$  runoff is relatively constant until it approaches 100. This coefficient is added to the soil data after the infiltration rates for each soil record in the site file. See Figure 2-6.

Next the surplus water input (non-infiltrated) from the plot is calculated by subtracting the actual infiltration from the water input

$$q_{surplus} = Wi - Ir \times fs \text{ if } Ir \times fs \leq Wi$$

$$= 0 \text{ otherwise}$$
(39)

where  $W_i$  is the water available for input. This surplus water is tallied as runoff. Next, if the surplus exceeds the water available from the pond, then the difference is used as a pond loss due to infiltration.

## 2.5 New output file z.envtr: environmental conditions tracer

As already mentioned, in addition to the output files produced by ZELIG, FACETA includes several new files. One of these is an environmental tracer file that is produced at the same frequency as the z.tracer file.

Yr	Row	Col	BGS	EGS	DGS	DegDay	PET	AET	RunOn	Rain	RunOff	Perc	Intrp	DDS	DDT	WDS	WDT
1	10	1	1.	365.	365.	7048.	140.2	99.4	0.0	138.2	0.0	40.8	0.0	0.20	0.03	0.50	0.50
2	10	1	1.	365.	365.	7117.	141.1	99.7	0.0	137.0	0.0	37.3	0.0	0.23	0.03	0.42	0.42
3	10	1	1.	365.	365.	7094.	140.9	98.0	0.0	135.2	0.0	37.3	0.0	0.24	0.04	0.34	0.34
4	10	1	1.	365.	365.	7209.	142.2	98.4	0.0	142.6	0.0	44.2	0.0	0.26	0.04	0.42	0.42
5	10	1	1.	365.	365.	7170.	141.8	99.0	0.0	142.3	0.0	43.4	0.5	0.24	0.04	0.42	0.42

Header Nomenclature

Code	Description
Yr	Simulation year
Row	Row of plot
Col	Col of plot
BGS	Day of beginning of growth seson
EGS	Day of End of growth season
DGS	Duration of degree season (l days)
DegDay	Degree-days for the year
PET	Potential ET for the year in Cm)
AET	Actual ET for the year (in Cm)
RunOn	Additional amount of water from terrain position and from up in the columns
Rain	Rainfall (in cm)
RunOff	Runoff from the plot in cm(if last row, this is runoff from column)
Perc	Deep percolation from plot in cm
Intrp	Canopy rainfall Inteceptio at the plot (in cm)
DDS	Dry-days for seedlings
DDT	Dry-days for trees
WDS	Wet-days for seedlings
WDT	Wet-days for trees

The other one is wsurf.out that tracks the balance at the surface on a daily basis.  
[Here describe the file.](#)

### 2.5.1.1 Percolation and soil water dynamics

Each soil layer is characterized by field capacity (fc), wilting point (wp), the extractable fraction wk (75% of fc), saturation (fraction of pore space given by porosity), and the total depth as illustrated in Figure 2-9.

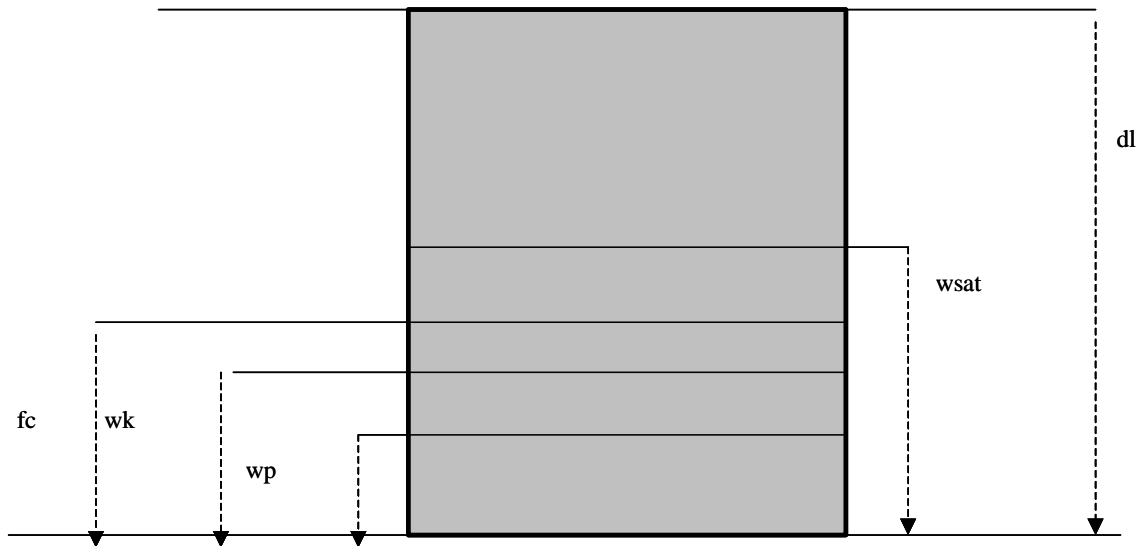


Figure 2-9 Volumetric parameters for each layer

Parameters dl, fc, wp are specified for each layer in the soils file. The parameter wk is calculated as 75% of fc and wsat as porosity × dl.

```

8 10.00 0.10 25.00 6.00 1.00 af/am
10.00 1.67 0.71 10.00
10.00 1.76 0.76 10.00
10.00 1.80 0.98 10.00
10.00 2.01 1.04 5.00
10.00 2.15 1.06 5.00
20.00 3.05 1.60 60.00
20.00 1.88 1.12 60.00
80.00 3.73 0.61 60.00
    
```

First row has # layers, fertility, fast flow fraction, dry infilt rate, sat infilt rate, slippery, soil type

Each row is layer depth, field capa, wil point and hydraulic conductivity, all in cm

In addition, for each soil layer FACETA requires a value for **hydraulic conductivity at saturation**. It is given after fc and wilting point. It is given in cm/hr.

### 2.5.1.2 Water table

Currently FACETA does not include water table dynamics for interaction with soil water. Although this is an important component in many systems, for the simulations we are conducting water table is decoupled from soil water. For example, in Caparo there are 3 major positions: banco, subbanco y bajio. In banco, the soil is deep and sandy; the water percolates from the last soil layer as deep loss and the water table is deep enough that it does not affect this flow. In subbanco, the deep flow typically becomes subsurface lateral flow with no impact from water table, in bajio the last soil layer is impervious preventing deep loss and also decoupling the soil from the water table. Future versions of FACETA

will include water table dynamics. One way of doing this is to include seasonal position of water table according to terrain position.

## 2.6 Species response

Drought days in ZELIG V. FACET 2.4 are calculated by accumulating dry days in the growing season by the total number of days in the growing season. The original ZELIG V. FACET 2.4 factor number of dry days was not modified in FACETA. For ease of reference the response of dry days is

$$Md = \begin{cases} \sqrt{\frac{du-d}{d}} & \text{for } 0 \leq d \leq du \\ 0 & \text{otherwise} \end{cases} \quad (40)$$

where  $d$  is the proportion of dry days in the growing season (in the interval  $[0,1]$ ),  $du$  is the upper tolerances to dry days and  $Md$  will be the multiplier (also in the range  $[0,1]$ ) for species response to dry days.

In Figure 2-10 an example is shown for illustration purposes of this growth rate multiplier for two contrasting species with parameter values  $du=0.22$  (for a drought intolerant) and  $du=0.8$  (for a drought tolerant).

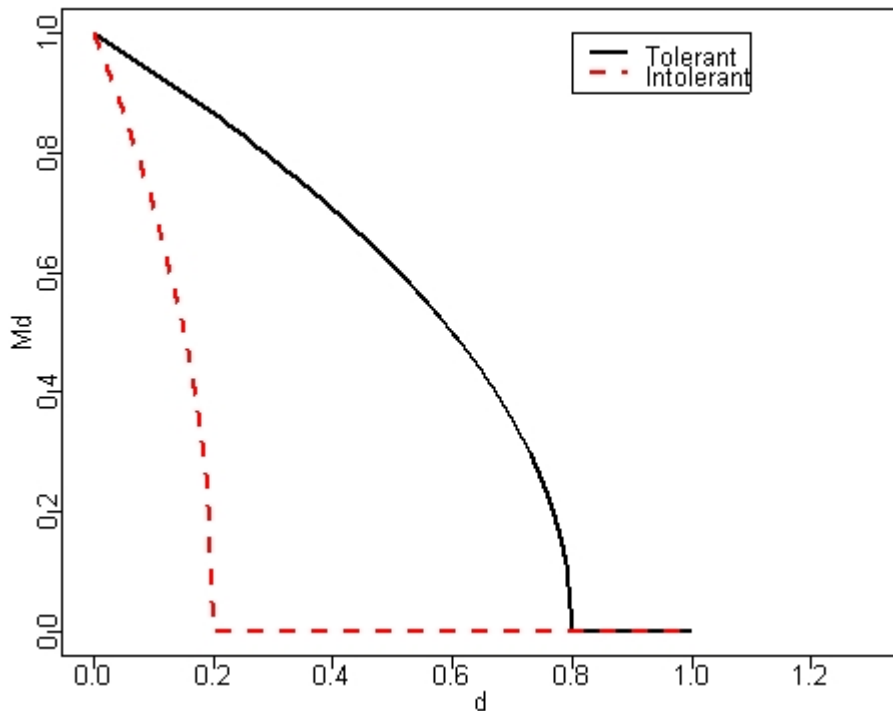


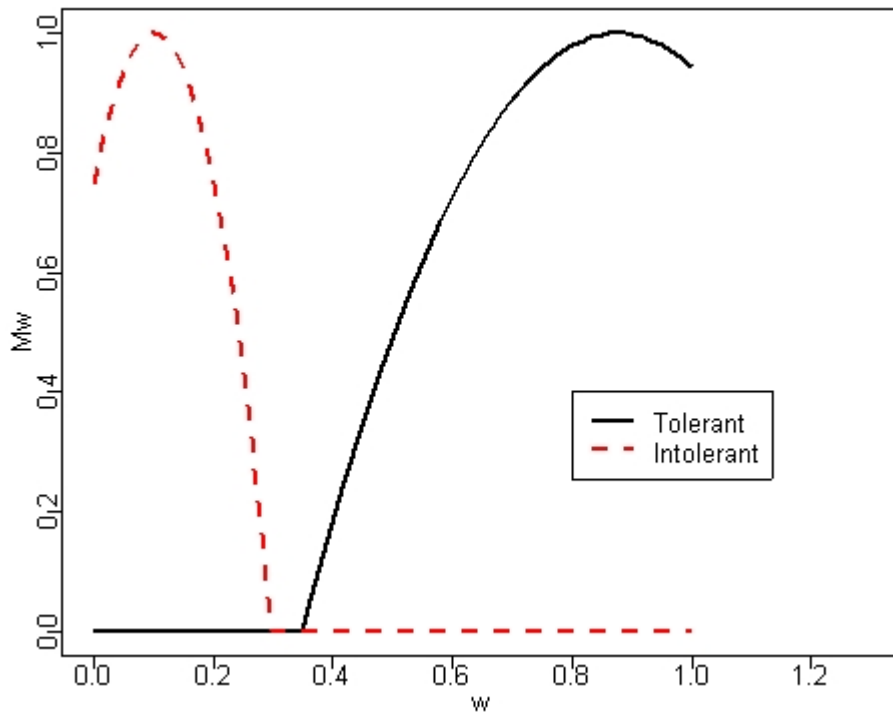
Figure 2-10 Dry days or drought response

In FACETA parabola function similar to the one employed for degree-days is calculated based on a species preference for wet days. That is to say

$$M_w = 4 \frac{(wu - w)(w - wl)}{(wu - wl)^2} \quad (41)$$

where  $w$  is the proportion of wet days in the growing season (in the interval  $[0,1]$ ),  $wu$  and  $wl$  are the upper and lower tolerances to wet days and  $M_w$  will be the multiplier (also in the range  $[0,1]$ ) for species response to wet days. Note that the optimum response would occur at half the distance between the two tolerance parameters  $wl$  and  $wu$ , this is to say at  $w=(wu+wl)/2$ .

In Figure 2-11 an example is shown for illustration purposes of this growth rate multiplier for two contrasting species with parameter values  $wl= 0.35$  and  $wu=1.4$  (for a wet-days tolerant) and  $wl= -0.1$  and  $wu=0.3$  (for a wet-days intolerant). In this case the tolerant species will show optimum response at  $w=(1.4+0.35)/2=0.875$  and the intolerant species will show optimum response at  $w=(0.3-0.1)/2=0.1$ .



**Figure 2-11 Wet days response**

Then the final growth multiplier for soil water is calculated from the minimum of the wet days and the dry days factors. Thus it becomes

$$M_{sw} = \min(M_d, M_w) \quad (42)$$

For example, for the species shown above, if the dry days and wet days factors are equal to 0.1, then  $M_d=0.93$  and  $0.71$  for the drought tolerant and the intolerant respectively. And for the same values  $M_w= 1$  and  $0$  for the wet intolerant and tolerant respectively. Upon taking the minimum following equation (42), then  $M_{sw}=0.93$  and  $0.0$  for the drought tolerant and the wet tolerant respectively. In this example growth rate would be very restricted for the wet tolerant because of the low number of wet days.

The same response is used for seedlings and trees. This is how ZELIG V. FACET 2.4 implemented the drought days and we maintained that idea for the wet day response. However, the drought factor and the saturation factor are not the same for seedlings and trees. Seedlings integrate soil moisture down to 20 cm of soil whereas trees integrate to the entire soil column.

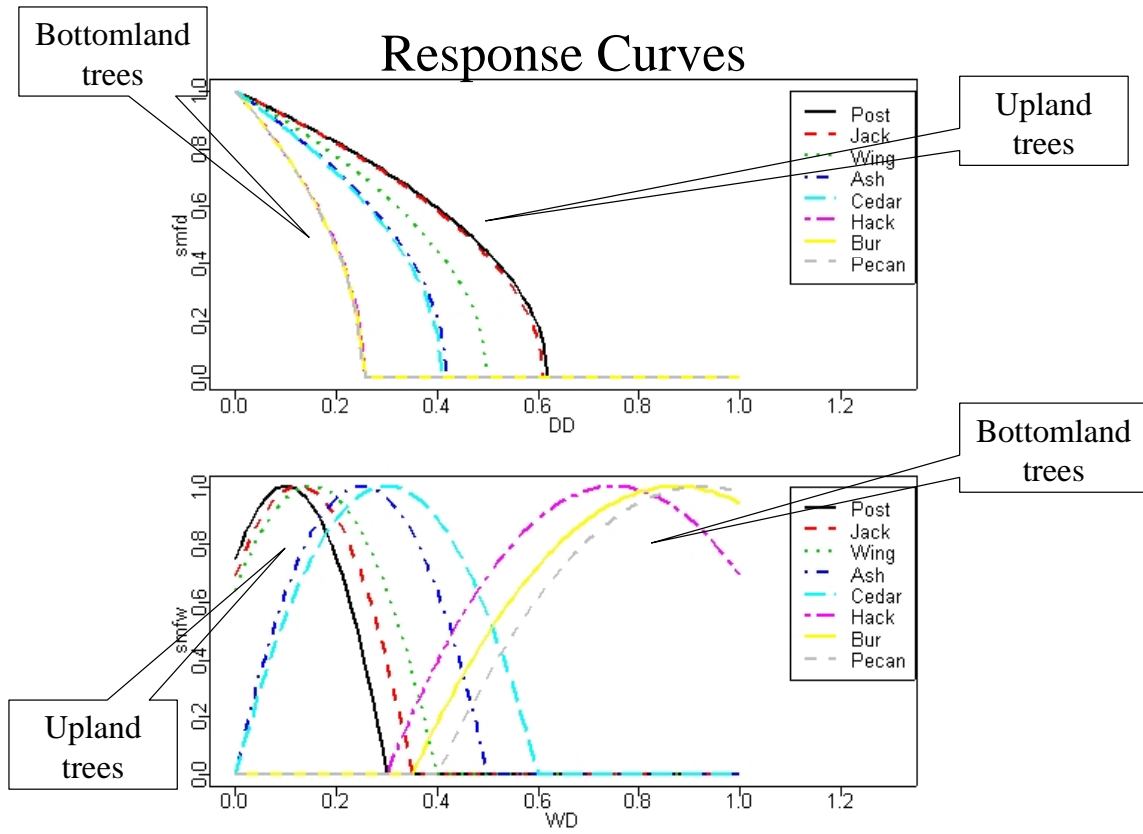
### 2.7 Species response for bottomland forests

In this document we will explain these parameters with eight species of bottomland forest in the Greenbelt Corridor of The Trinity River, North Texas. In this case some of the species are considered typical of bottomland and others of upland conditions. The later are drought tolerant but saturation intolerant species whereas the former species are drought intolerant and saturation tolerant. See Table 2.

**Table 2 Species used in greenbelt corridor North Texas**

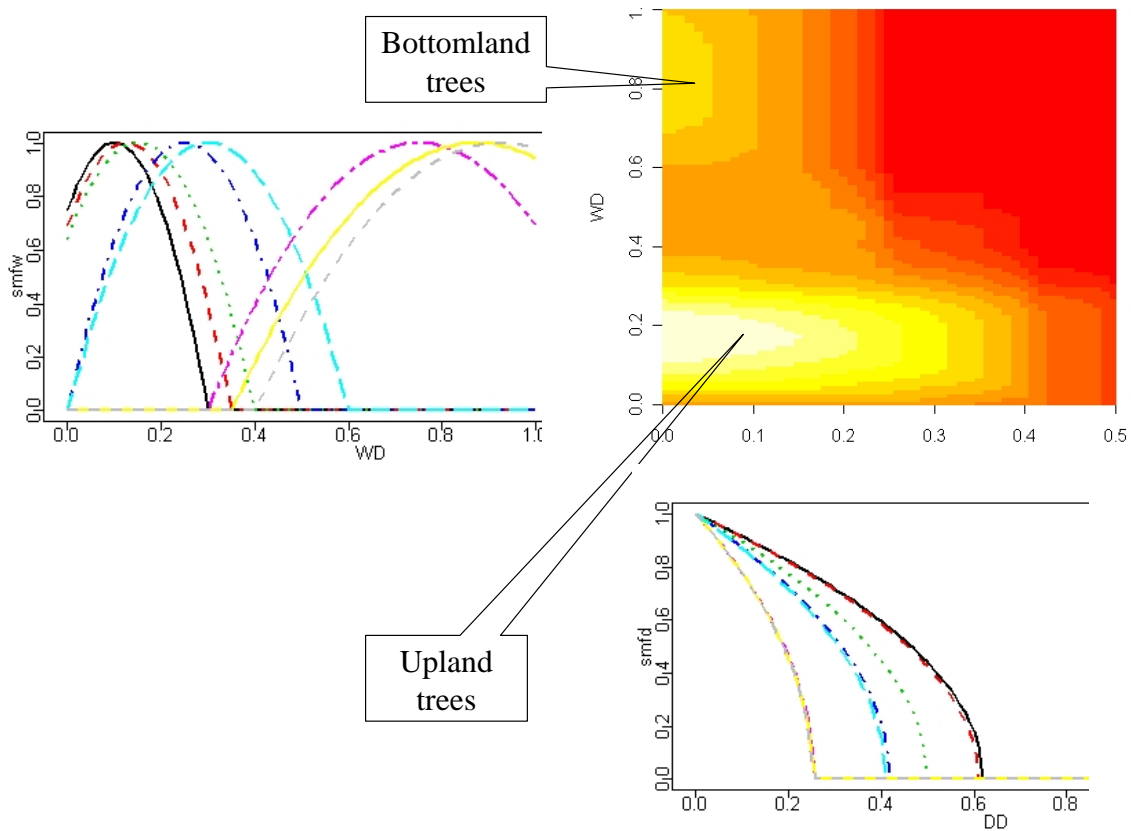
<b>Name</b>	<b>Common name</b>	<b>Condition</b>	<b>du</b>	<b>Wl</b>	<b>wu</b>
	Post oak	Upland	0.62	-0.1	0.3
	Black jack oak	Upland	0.61	-0.1	0.35
	winged elm	Upland	0.5	-0.1	0.4
	green ash	Bottomland	0.42	0.0	0.5
	cedar elm	Bottomland	0.41	0.0	0.6
	Sugarberry	Bottomland	0.254	0.3	1.2
	bur oak	Bottomland	0.252	0.35	1.4
	Pecan	Bottomland	0.251	0.4	1.45

The response curves for these parameters values are shown in Figure 2-12



**Figure 2-12 Soil Moisture response dry days (Dd) and Wet-Days (wd)**

Once the minimum is found the response can be seen in a dry-days and wet-day plane.



**Figure 2-13 Response in dry-day and wet day plane.**

The dry-days and wet days calculated during a simulation of flat terrain (slope=0%), flow accumulation or catchment area of  $A=100$  and percent of runoff  $C=1\%$  is shown in Figure 2-14.

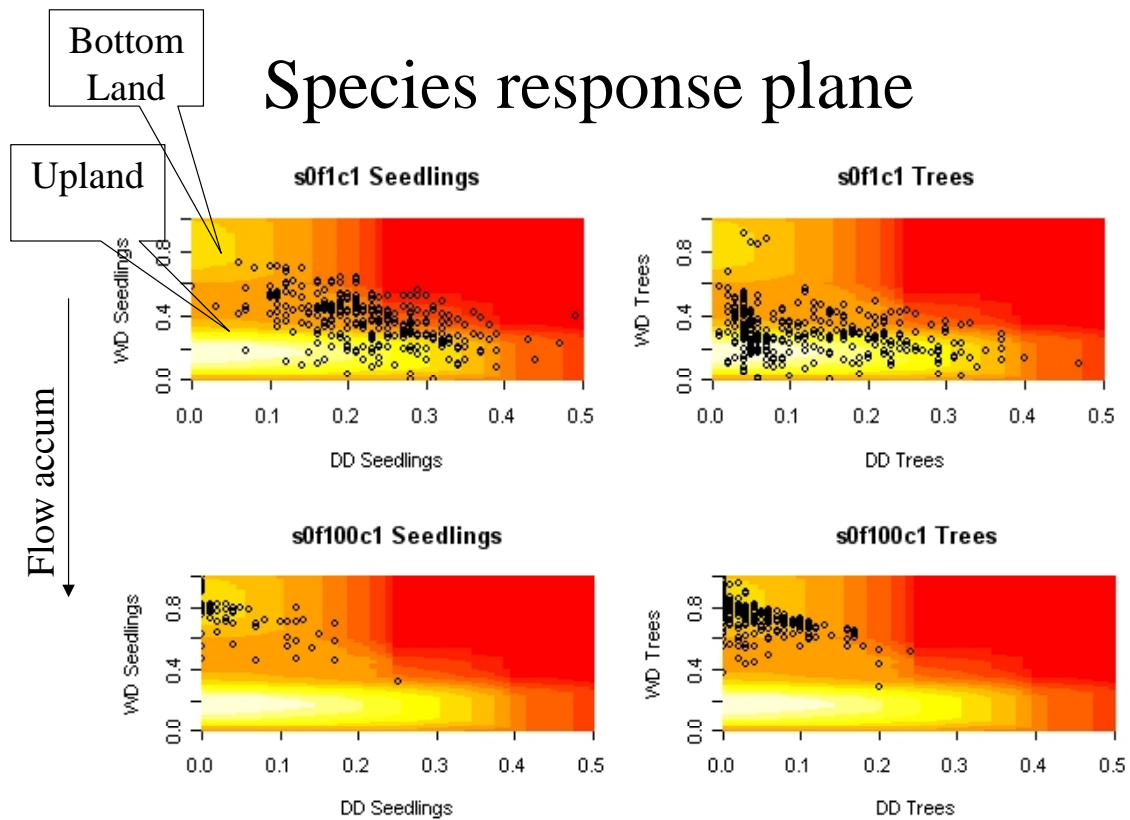


Figure 2-14 An example of species response plane

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