CWEMF
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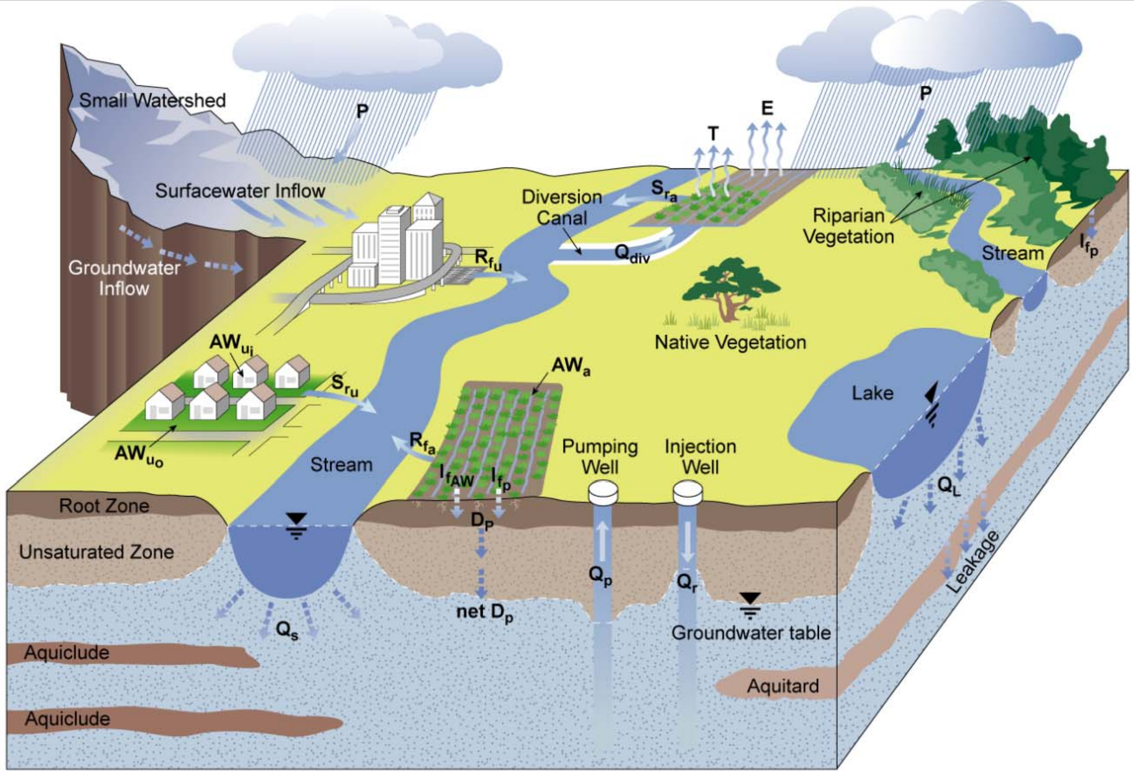
Session 4:

Routing of Water through Land Surface, Root Zone and Unsaturated Zone

IWFM Components



LEGEND

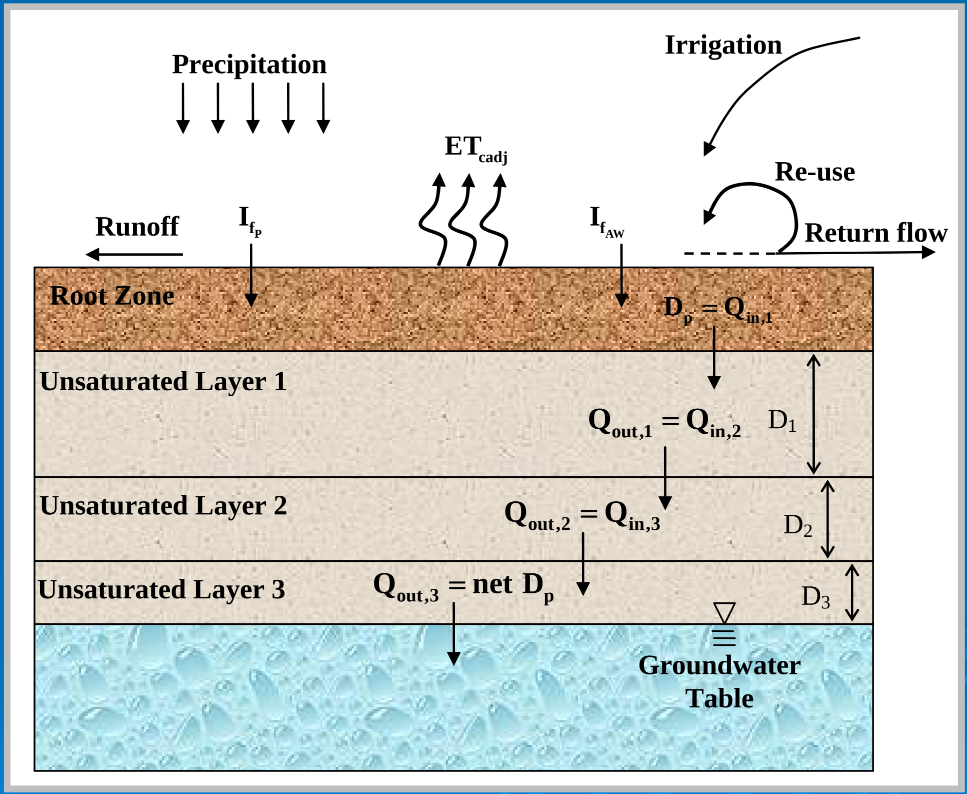
- P........... *Precipitation*
- AW_a..... *Water applied to agricultural lands*
- AW_{u_i}.... *Water applied to indoor urban lands*
- AW_{u_o}... *Water applied to outdoor urban lands*
- E........... *Evaporation*
- T........... *Transpiration*
- I_{f_p}......... *Infiltration of precipitation*
- $I_{f_{AW}}$..... *Infiltration of applied water*
- Q_{div}...... *Surface water diversion*
- S_{r_a}........ *Agricultural runoff*
- S_{r_u}........ *Urban runoff*
- R_{f_a}........ *Agricultural return flow*
- R_{f_u}........ *Urban return flow*
- D_P......... *Deep percolation of water to the unsaturated zone*
- net D_p... *Recharge to the groundwater aquifer*
- Q_p......... *Pumping from groundwater aquifer*
- Q_r......... *Recharge to groundwater aquifer*
- Q_s......... *Stream-groundwater interaction*
- Q_L......... *Lake-groundwater interaction*

Land Surface and Root Zone Component

- Land surface and root zone component (a.k.a. IDC) makes IWFM a powerful tool:
  - Computes lateral inflows to streams and recharge to groundwater as a function of climate, land use distribution, soil parameters and agricultural water management practices
  - Computes urban water demand based on population and per capita water use, and agricultural water demand based on climate, crop characteristics, soil parameters and agricultural water management practices
  - Allows meeting water demands through stream diversions and groundwater pumping
  - Computes stresses on streams and groundwater due to diversions and pumping
  - Can be used to simulate effects of a variety of water management scenarios on the water resources of a basin

Land Surface, Root Zone and Unsaturated Zone Processes

- Precipitation and irrigation less direct runoff and return flow is the inflow into root zone
- Deep percolation from root zone is the inflow into unsaturated zone
- Net deep percolation from unsaturated zone is the recharge to groundwater
- Unsaturated zone layer thicknesses are time-dependent as elevation of groundwater table increases and decreases



Land Surface and Root Zone Component

- 4 general land-use types can be simulated:
  - Non-ponded agricultural crops
  - Ponded agricultural crops
  - Urban lands
  - Native and riparian vegetation
- 5 types of ponded crop lands can be simulated:
  - Rice with flooded decomposition
  - Rice with non-flooded decomposition
  - Rice with no decomposition
  - Seasonal refuges (i.e. managed wetlands)
  - Permanent refuges
- As many non-ponded agricultural crop lands as specified by the user can be simulated

Land Surface and Root Zone Component

- Simulation of land surface and root zone flow processes are done at each grid cell for each land-use type
- One-dimensional simulation of soil moisture movement in the vertical
- Time-series land-use acreages can be simulated; e.g. a particular crop acreage can appear or disappear during a simulation period
- Simulation of ETAW and effective precipitation
- Simulation of re-use of irrigation return flow that takes place at a grid cell, between grid cells or between subregions
- Ability to simulate a variety of irrigation methods and agricultural water management practices such as regulated deficit irrigation and irrigation for the leaching of salts

Soil Moisture Routing

- Governing conservation equation (implicit scheme; all flow terms are computed at time step t+1):

$$\left(\theta Z\right)^{t+1} = \left(\theta Z\right)^{t} + \Delta t\left(P - R_P + A_W - R_f + GZ - D_r - D - ET\right) + \Delta\theta_a$$

where

θ	=	soil moisture content, [L/L];
Z	=	root zone depth, [L];
P	=	precipitation, [L/T];
R_P	=	surface runoff from precipitation, [L/T];
A_W	=	applied water, [L/T];
R_f	=	net return flow of applied water, [L/T];
G	=	generic moisture source, [L/L/T];
D_r	=	pond drainage, [L/T];
D	=	deep percolation, [L/T];
ET	=	actual evapotranspiration, [L/T];
$\Delta\theta_a$	=	soil moisture change due to changing land use, [L];
Δt	=	time step length, [T];
t	=	time step counter (dimensionless).

Rooting Depth

$$\left(\theta Z\right)^{t+1}=\left(\theta Z\right)^{t}+\Delta t\left(P-R_{P}+A_{w}-R_{f}+GZ-D_{r}-D-ET\right)+\Delta\theta_{a}$$

- Constant for all land-use types except for non-ponded crops
- For non-ponded crops, it can *"optionally"* be a user-specified time-series data to represent the crop root growth
- CAUTION**:** If the rooting depth, Z, is set to zero (e.g. outside the cropping season), the moisture storage capacity of the soil will also be set to zero. This will have adverse effects on the initial moisture calculations at the beginning of the next cropping season

Infiltration and Direct Runoff due to Precipitation

$$(\theta Z)^{t+1} = (\theta Z)^{t} + \Delta t\left(P - R_P + A_w - R_f + GZ - D_r - D - ET\right) + \Delta\theta_a$$

- Precipitation, P, is user-specified time-series data
- All precipitation on impervious urban lands (rooftops, parking lots, etc.) become runoff
- For all other land-use types, original SCS method (USDA, 1985) is modified to compute direct runoff, R_P:

$$I_P = P - R_P \quad ; \quad R_P = \frac{1}{\Delta t}\frac{(P\Delta t - 0.2S)^2}{P\Delta t + 0.8S}$$

where
I_P = infiltration of precipitation, [L/T];
P = precipitation, [L/T];
R_P = direct runoff, [L/T];
S = retention parameter, (dimensionless).

Infiltration and Direct Runoff due to Precipitation

- Definition of retention parameter, S (Schroeder et al., 1994)

$$S = \begin{cases} S_{max}\left[1 - \dfrac{\theta^t - \dfrac{\theta_f}{2}}{\theta_T - \dfrac{\theta_f}{2}}\right] & \text{for} \quad \theta^t > \dfrac{\theta_f}{2} \\ S_{max} & \text{for} \quad \theta^t \leq \dfrac{\theta_f}{2} \end{cases}$$

$$S_{max} = \frac{1000}{CN} - 10$$

- In other words, rainfall infiltration is at its maximum when moisture content is at or below half of field capacity, and decreases linearly as moisture content increases

Applied Water and Net Return Flow

$$(\theta Z)^{t+1} = (\theta Z)^{t} + \Delta t \left(P - R_P + A_w - R_f + GZ - D_r - D - ET \right) + \Delta\theta_a$$

- Applied water, A_w, can be a combination of stream diversions and groundwater pumping
- Applied water is zero for native and riparian vegetation
- For urban lands, applied water is distributed between urban indoors and urban outdoors based on user-defined time-series fractions

Applied Water and Net Return Flow

$$(\theta Z)^{t+1} = (\theta Z)^{t} + \Delta t \left(P - R_P + A_w - R_f + GZ - D_r - D - ET \right) + \Delta\theta_a$$

- For urban indoors, net return flow, R_f, equals applied water
- For non-ponded crops and urban outdoors, net return flow is computed as a fraction of applied water:

$$R_f = A_w \left(f_{R_{f,ini}} - f_U \right)$$

$$f_{R_{f,ini}} = \text{initial return flow fraction } \left(0 \le f_{R_{f,ini}} \le 1 \right)$$

$$f_U = \text{reuse fraction } \left(\le f_{R_{f,ini}} \right)$$

- For ponded crops, net return flow is computed based on initial return flow and re-use rates:

$$R_f = R_{f,ini} - U$$

Generic Moisture Source

$$\left(\theta Z\right)^{t+1} = \left(\theta Z\right)^{t} + \Delta t\left(P - R_P + A_w - R_f + GZ - D_r - D - ET\right) + \Delta\theta_a$$

- User-specified moisture source in addition to precipitation and irrigation
- Examples:
  - Fog
  - Seepage into model domain from surrounding channels (e.g. Sacramento-San Joaquin Delta islands)
- Equals zero in most applications

Pond Drainage

$$\left(\theta Z\right)^{t+1} = \left(\theta Z\right)^{t} + \Delta t\left(P - R_P + A_w - R_f + GZ - D_r - D - ET\right) + \Delta\theta_a$$

- Used only for ponded crops
- Calculated based on user-specified time-series pond depths:

$$D_r = \frac{P_D^t - P_D^{t+1}}{\Delta t} \geq 0$$

where P_D = pond depth, [L].

Deep Percolation (van Genuchten-Mualem Equation)

$$\left(\theta Z\right)^{t+1} = \left(\theta Z\right)^{t} + \Delta t\left(P - R_P + A_W - R_f + GZ - D_r - D - ET\right) + \Delta\theta_a$$

- Conservation of momentum:

$$D = K_u\left(\theta Z\right)\frac{dh\left(\theta Z\right)}{dz} \cong D_{rdc} + K_s\left(\frac{\theta}{\theta_T}\right)^{1/2}\left\{1 - \left[1 - \left(\frac{\theta}{\theta_T}\right)^{1/m}\right]^m\right\}^2$$

$$m = \frac{\lambda}{\lambda + 1} \quad ; \quad D_{rdc} = \begin{cases} \theta^t\left(Z^t - Z^{t+1}\right) & \text{if } Z^t > Z^{t+1} \\ 0 & \text{otherwise} \end{cases}$$

where K_s = saturated hydraulic conductivity, [L/T];

λ = pore size distribution index, [dimensionless];

Z = rooting depth, [L]

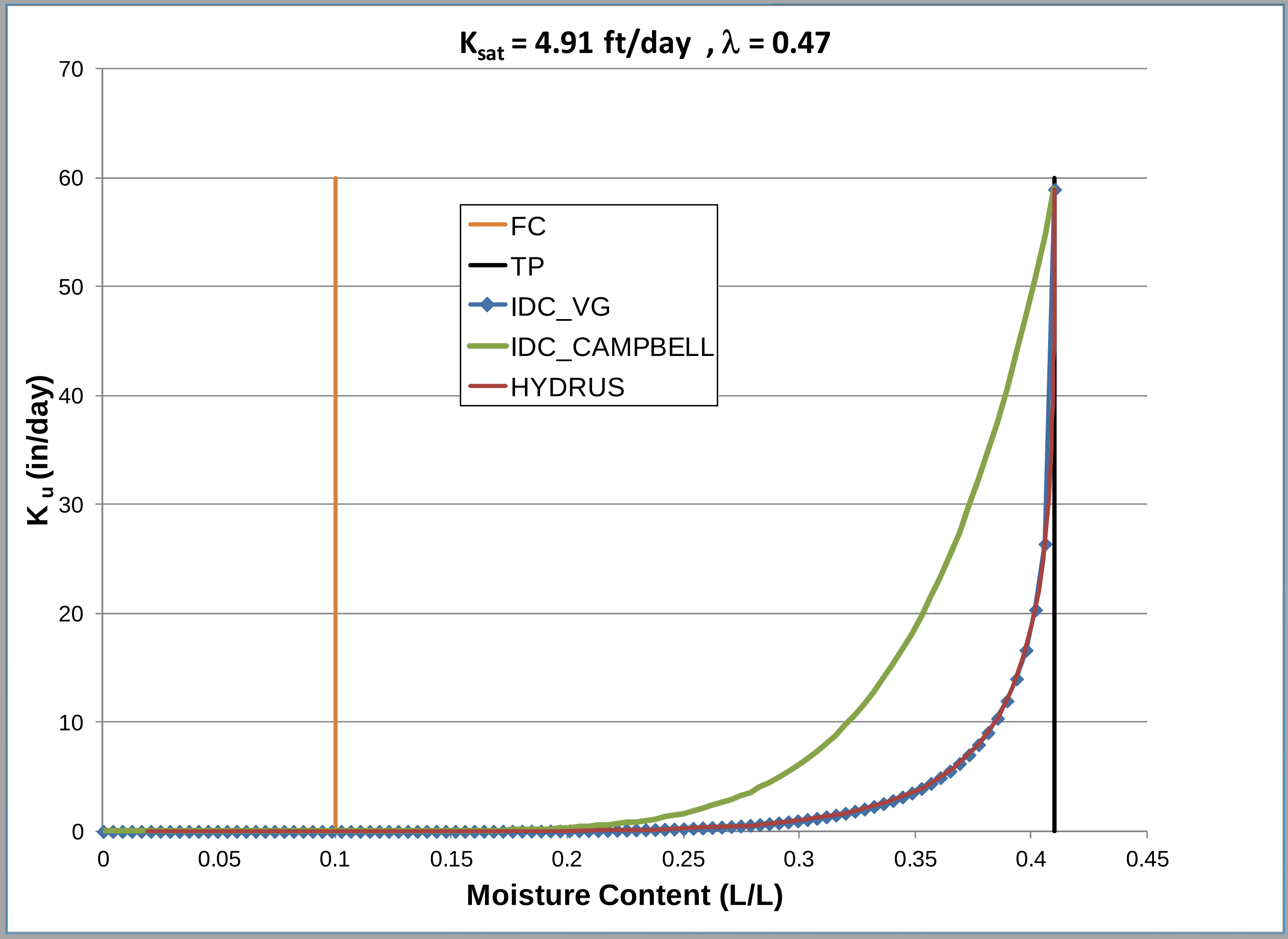
Deep Percolation (Campbell Equation)

$$\left(\theta Z\right)^{t+1} = \left(\theta Z\right)^{t} + \Delta t\left(P - R_P + A_W - R_f + GZ - D_r - D - ET\right) + \Delta\theta_a$$

- Conservation of momentum:

$$D \cong D_{rdc} + K_s\left(\frac{\theta}{\theta_T}\right)^{3+\frac{2}{\lambda}}$$

Deep Percolation:
Campbell vs. van Genuchten-Mualem



Deep Percolation

$$\left(\theta Z\right)^{t+1} = \left(\theta Z\right)^{t} + \Delta t\left(P - R_p + A_w - R_f + GZ - D_r - D - ET\right) + \Delta\theta_a$$

- IWFM assumptions:
  - unit vertical hydraulic gradient (Schroeder et al. 1994)
  - negligible residual water content

Evapotranspiration (Allen et al., 1998)

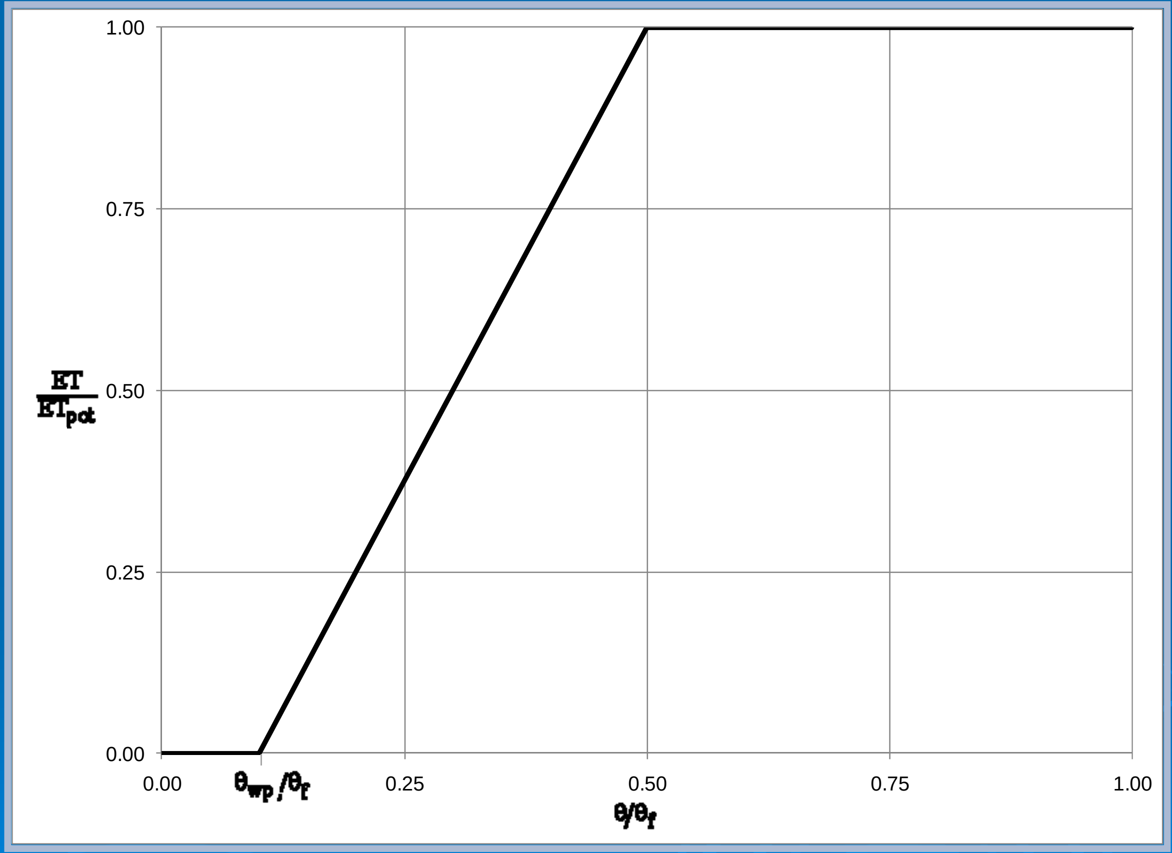
$$\left(\theta Z\right)^{t+1} = \left(\theta Z\right)^{t} + \Delta t\left(P - R_P + A_w - R_f + GZ - D_r - D - ET\right) + \Delta\theta_a$$

$$ET = \begin{cases} ET_{pot} & \text{if} \quad \dfrac{\theta - \theta_{wp}}{\frac{\theta_f}{2} - \theta_{wp}} > 1 \\ \dfrac{\theta - \theta_{wp}}{\frac{\theta_f}{2} - \theta_{wp}} ET_{pot} & \text{if} \quad 0 \le \dfrac{\theta - \theta_{wp}}{\frac{\theta_f}{2} - \theta_{wp}} \le 1 \\ 0 & \text{if} \quad \dfrac{\theta - \theta_{wp}}{\frac{\theta_f}{2} - \theta_{wp}} < 0 \end{cases}$$

Evapotranspiration

Assumptions:

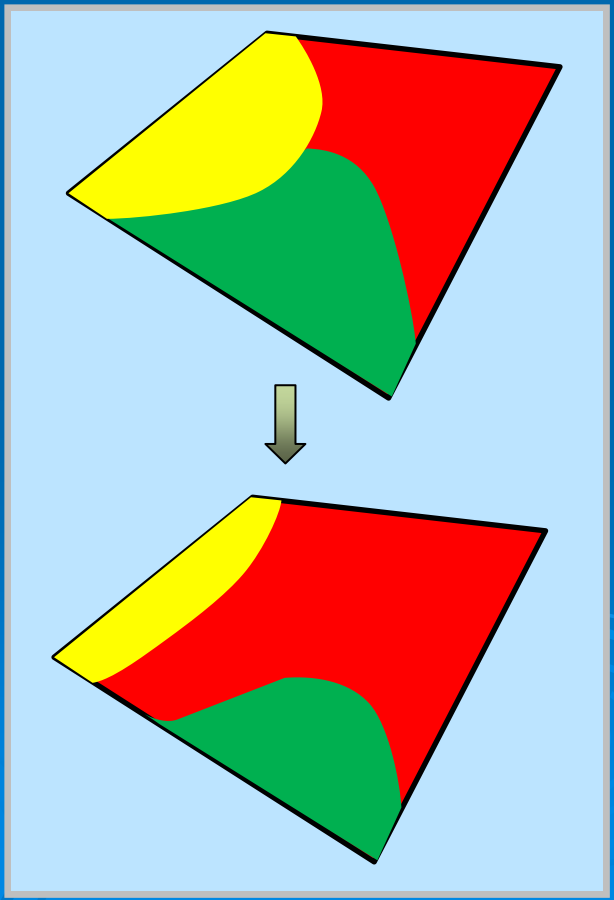
- p is taken as 0.5
- ET_{pot} can be taken as ET_c, ET_{cadj} or whatever is specified by the user
- IWFM only simulates the effect of water stress on the actual ET; all other stresses on the crop must be incorporated into ET_{pot} by the user



Change in Moisture Due to Area Change

$$(\theta Z)^{t+1} = (\theta Z)^{t} + \Delta t\left(P - R_P + A_w - R_f + GZ - D_r - D - ET\right) + \Delta\theta_a$$

- Introduced to maintain the mass balance when land-use acreages change during simulation period
- When area of a land-use type decreases it is zero
- When area of a land-use type increases, moisture from other land-uses are assimilated and it is non-zero



Destination for Surface Runoff

$$\left(\theta Z\right)^{t+1} = \left(\theta Z\right)^{t} + \Delta t\left(P - R_p + A_w - R_f + GZ - D_r - D - ET\right) + \Delta\theta_a$$

- Surface runoff, i.e. combination of direct runoff and net return flow, from a grid cell can be sent to
  - Outside model domain
  - A stream node
  - Another grid cell
  - A subregion
  - A lake
  - Groundwater in the same cell as recharge

Moisture Routing in Unsaturated Zone

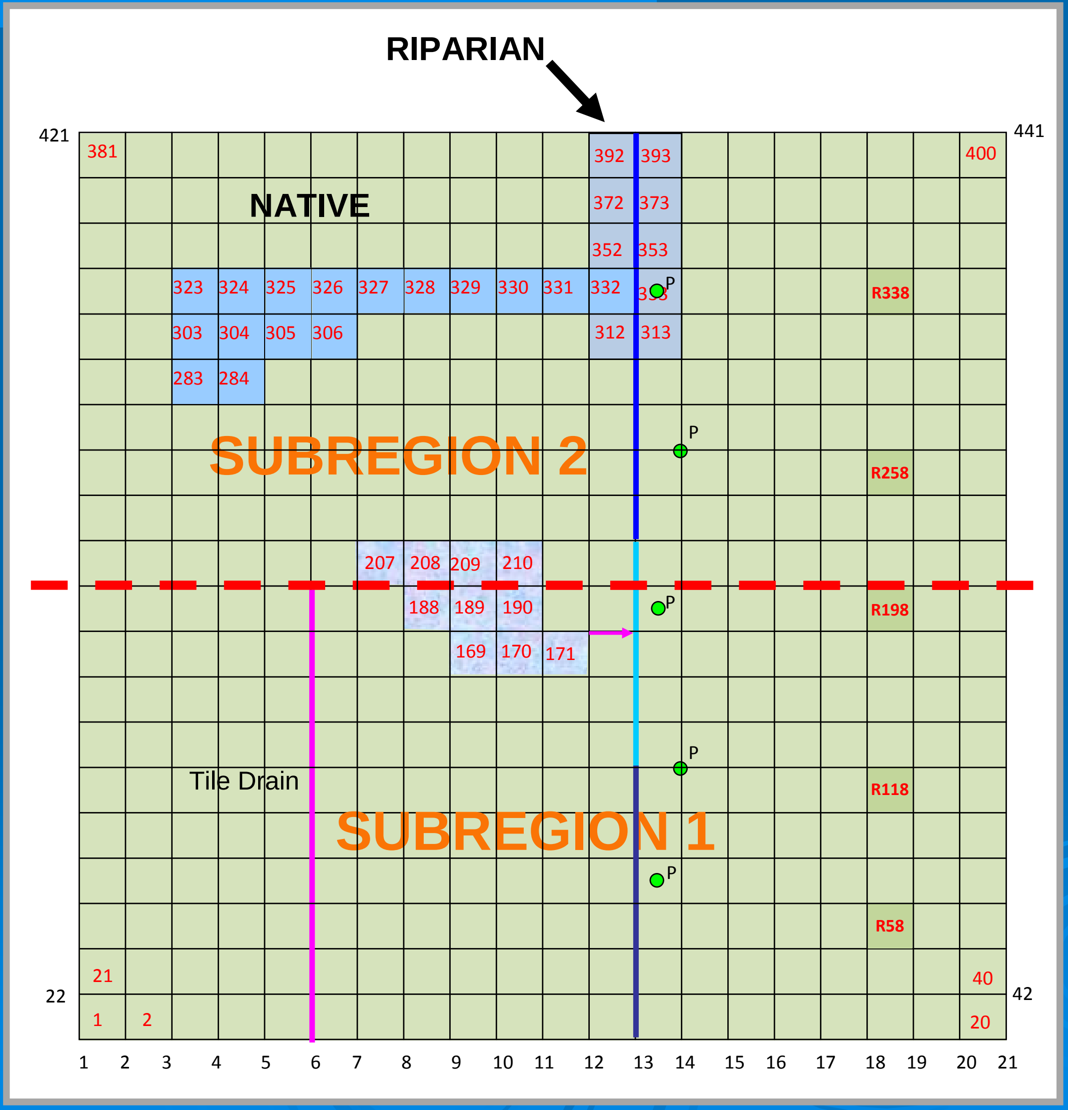
- Unsaturated zone simulation is optional (i.e. number of unsaturated layers can be set to zero)
- One-dimensional moisture routing in the vertical through each unsaturated zone layer
- Thickness of layers can change with the rise and fall of the groundwater table
- The same method used for routing moisture through root zone is also used for each unsaturated layer:

$$\left(\theta_u Z_u\right)^{t+1} = \left(\theta_u Z_u\right)^{t} + \Delta t\left(Q_{in} - Q_{out}\right)^{t+1}$$

where Q_{in} = inflow from the top layer, [L/T],

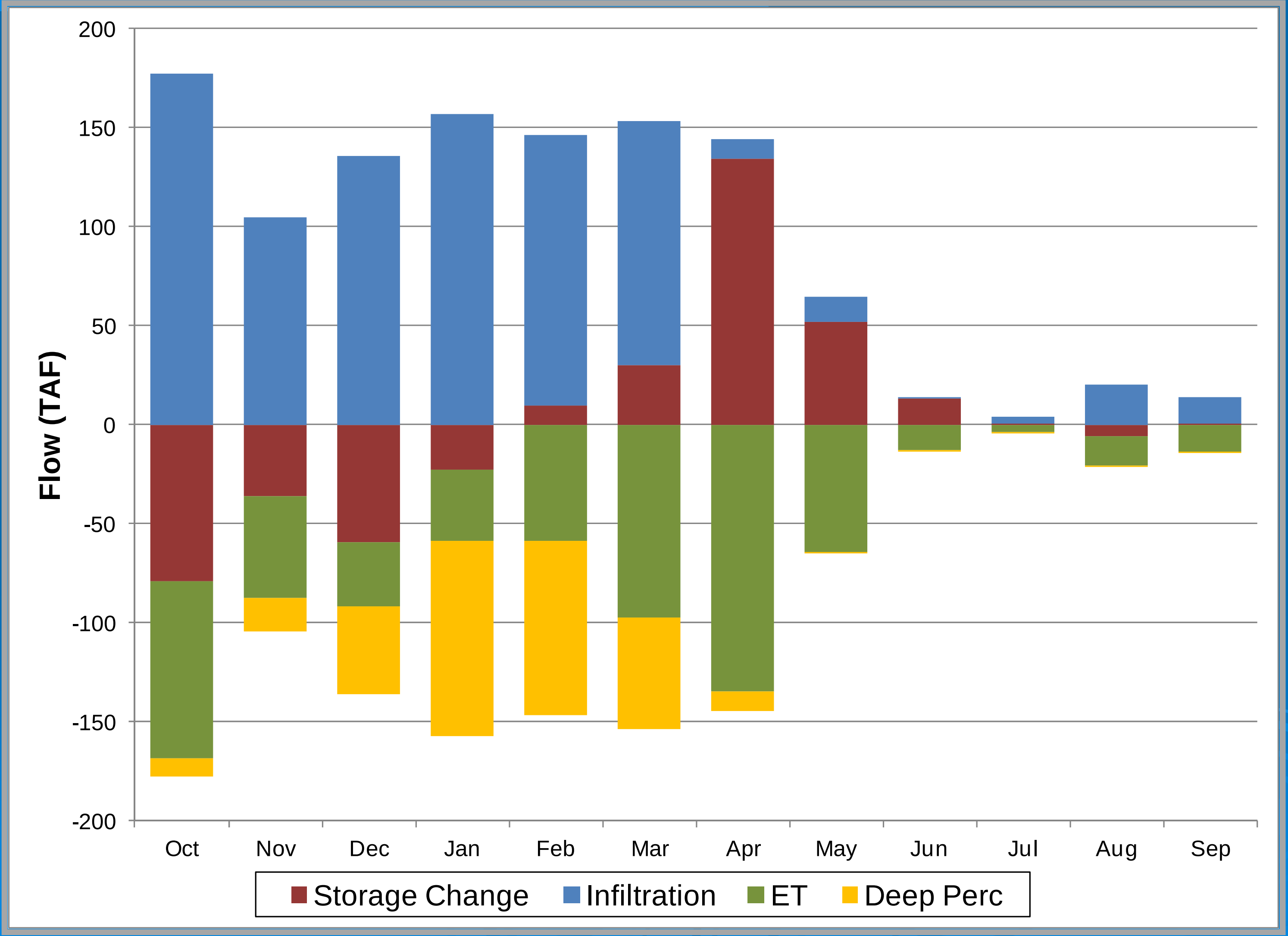
Q_{out} = outflow from the layer computed using either van Genuchten-Mualem or Campbell equations, [L/T]

Example 4

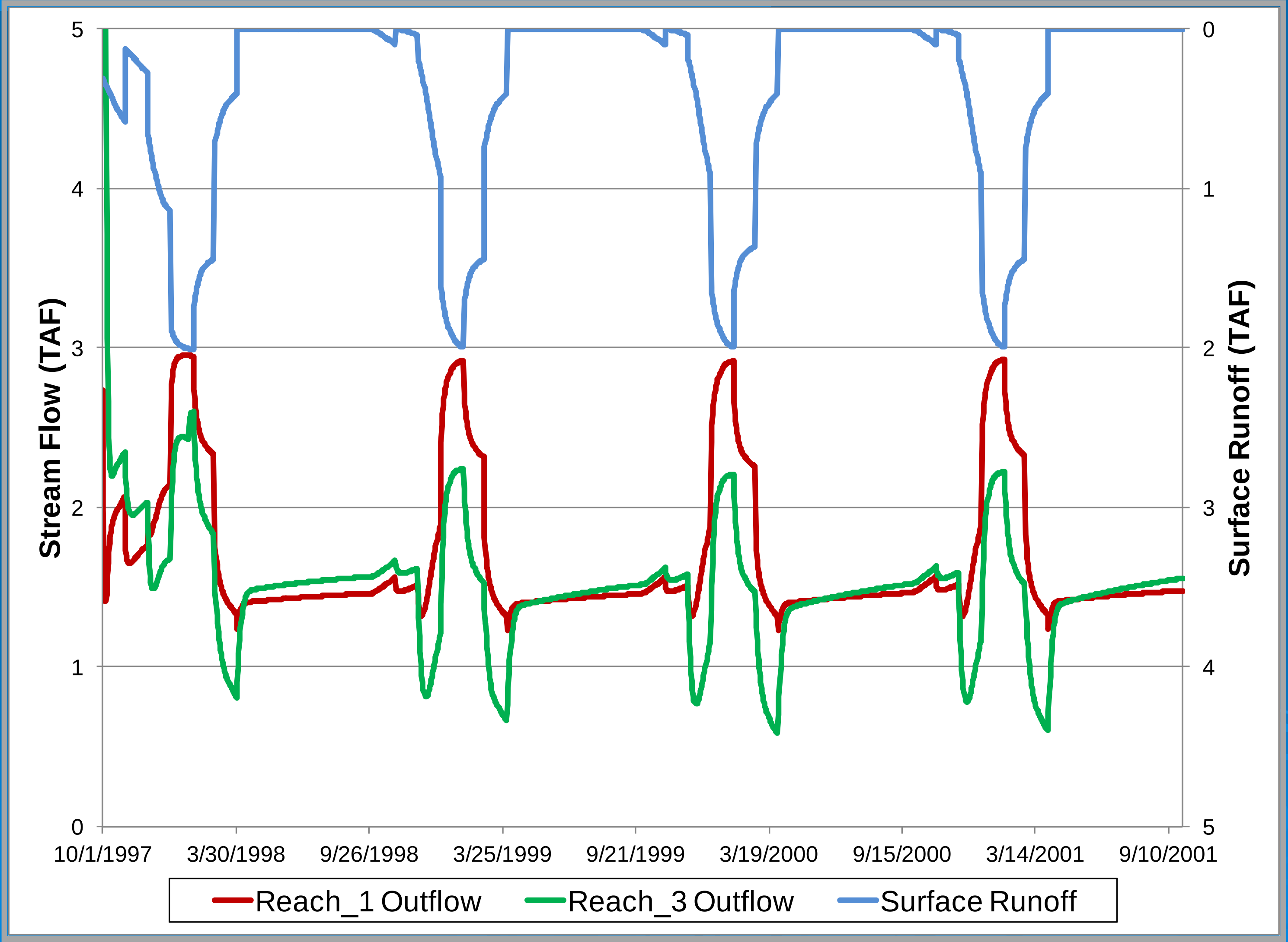


RIPARIAN
NATIVE
SUBREGION 2
SUBREGION 1
Tile Drain
421
441
22
42
381
400
392
393
372
373
352
353
323
324
325
326
327
328
329
330
331
332
R338
303
304
305
306
312
313
283
284
R258
207
208
209
210
188
189
190
R198
169
170
171
R118
R58
21
40
1
2
20
P
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21

Example 4:
Root Zone Average Monthly Water Budget



Example 4:
Surface Runoff into Stream



Example 4:
Deep Percolation versus Net Deep Percolation