HYMO: Process Description

I Water Balance on the Hydrotope/Municipio - Scale

1. Evapotranspiration:

Penman approach for potential ET:

$$PET = \frac{\delta \cdot R_n + c_p \cdot \rho_a \cdot (e_s - e_{act})/r_a}{(\delta + \gamma) \cdot L_V} \tag{1}$$

where:

PET	=	**potential evapotranspiration**
R_n	=	**Net Radiation = f(cloudyness, surface albedo, ...)**
$e_s - e_{act}$	=	**air moisture saturation deficit = f(air temperature, air humidity)**
r_a	=	**aerodynamic resistance = f(wind velocity)**

non-linear reduction of PET (from the HAPEX-SAHEL study):

$$AET = 0.75 \cdot PET \cdot (1 - \beta_{hum}) \cdot (2.7 - 1.7 \cdot \beta_{hum}) \tag{2}$$

$$\beta_{hum} = \frac{\theta_{FC} - \theta_{act}}{\theta_{FC} - \theta_r} \tag{3}$$

where:

AET	=	**actual evapotranspiration**
β_{hum}	=	**reduction coefficient**
θ_{act}	=	**actual soil moisture**
θ_{FC}	=	**soil moisture at field capacity**
θ_r	=	**residual soil moisture**

2. Soil Water Balance:

Bucket approach with threshold values $\theta_s, \theta_{FC}, \theta_r$*:*

$$\theta_r \leq \theta_{act} \leq \theta_s \tag{4}$$

$$\theta_{act}(t + \Delta t) = \theta_{act}(t) + N/\Delta t \tag{5}$$

$$q_o = \begin{cases} 0 & \textbf{for} \quad \theta_{act}(t) + N/\Delta t \leq \theta_s \\ (\theta_{act}(t) + N/\Delta t) - \theta_s & \textbf{for} \quad \theta_{act}(t) + N/\Delta t > \theta_s \end{cases} \tag{6}$$

$$q_{gw} = \begin{cases} 0 & \textbf{for} \quad \theta_{act}(t) + N/\Delta t \leq \theta_{FC} \\ (\theta_{act}(t) + N/\Delta t) - \theta_{FC} & \textbf{for} \quad \theta_{act}(t) + N/\Delta t > \theta_{FC} \end{cases} \tag{7}$$

$$q_l = f_{subfrac} \cdot q_{gw} \tag{8}$$

$$q_{deep} = (1 - f_{subfrac}) \cdot q_{gw} \tag{9}$$

where:

N	=	**precipitation**
q_o	=	**surface runoff**
q_{gw}	=	**percolation out of the topsoil** $(0 < q_{gw} < k_{sat})$
k_{sat}	=	**saturated conductivity**
q_l	=	**lateral subsurface flow**
q_{deep}	=	**deep groundwater recharge**
$f_{subfrac}$	=	**empirical factor**

3. **Water budget of distributed ponds (small acudes):**

Water balance accounting for inflow, outflow, water use, and evaporation:

$$S_{acude}(t+\Delta t) = S_{acude}(t) + q_{acude}^{in} - q_{acude}^{out} - watuse_{acude} - EV_{acude} \qquad (10)$$

where:

S_{acude}	=	**water volume in the pond**
q_{acude}^{in}	=	**surface flow into the pond** ($q_{acude}^{in} = f_{intercep} \cdot q_o$)
$f_{intercep}$	=	**empirical factor for water collection in the acudes**
q_{acude}^{out}	=	**outflow from the pond** ($0 < q_{acude}^{in} < q_o$)
$watuse_{acude}$	=	**water used from the acude (e.g. irrigation)**
EV_{acude}	=	**open water evaporation from the acude (= f(water surafce))**

4. **Runoff into the major rivers (only one river stretch per municipio), composed of:**

- **intercepted surface flow generated in the lowlands**
- **outflow from lowland acudes**
- **lateral subsurface flow in the lowlands**

$$q_{river} = (1 - (f_{intercep})_l) \cdot (q_o)_l + (q_{acude}^{out})_l + (q_l)_l \qquad (11)$$

where:

q_{river}	=	**runoff into the municipio's main river**
$(q_o)_l$	=	**surface runoff in the lowlands**
$(f_{intercep})_l$	=	**empirical factor for water collection in the acudes (lowlands)**
$(q_{acude}^{out})_l$	=	**outflow from the ponds (lowlands)**
$(q_l)_l$	=	**lateral subsurface flow (lowlands)**

II Routing in the River System (Scale of Large River Basins)

1. **The river network prescribes the water transfer system between all municipios**

   $\Longrightarrow$ *The municipios are connected by a dentritic river network*

2. **Routing process through a municipio is approached with a linear response function:**

$$Q_j^{out} = \sum_{i=1}^{j} Q_i^{in} \cdot h_{j-i+1} \tag{12}$$

where:

Q_j^{in}	=	**flow out of the municipio**
Q_j^{out}	=	**flow into the municipio**
h	=	**response function (hunit-hydrograph type:** $h_i > 0; \sum h_i = 1$**)**
j, i	=	**time interval (**Δt **= 1d)**

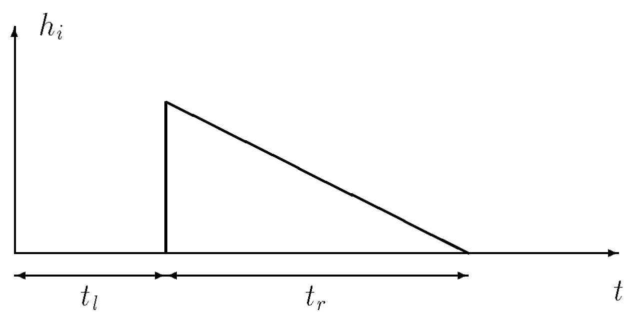

Figure 1: Scheme of the linear response function

where:

t_l	=	**lag time [d]**
t_r	=	**retention time [d]**

Assumption: $\mathbf{1d} \leq t_l + t_r \leq \mathbf{7d}$

$$t_l = \frac{\Delta s}{\overline{v}} \tag{13}$$

$$t_r = \frac{\Delta s}{v_m in} - \frac{\Delta s}{v_m ax} \tag{14}$$

where:

Δs	=	**channel length**
t_l	=	**lag time [d]**
t_r	=	**retention time [d]**

3. Flow velocity in the river

$\Longrightarrow$ *The flow velocity in the river by Manning equation:*

$$v = k_{St} \cdot \sqrt{S_0} \cdot \left(\frac{h \cdot B}{2h + B} \right)^{\frac{2}{3}} \tag{15}$$

where:

k_{St}	=	**roughness coefficient (Strickler coefficient** $[m^{1/3}/s]$
S_0	=	**channel slope [-]**
B	=	**channel width [m]**
h	=	**flow depth [m]**

$\Longrightarrow$ *Flow velocity: f(*k_{St}, S_0, h*, river cross section)*

Assumption:

$$v_{max} = v(h = h_{max})$$
$$\overline{v} = v(h = \tfrac{2}{3} h_{max})$$
$$v_{min} = v(h = \tfrac{1}{10} h_{max})$$

4. Estimation about the cross section of the river

$\Longrightarrow$ *approached given in the CREAMS–SWAT/GRASS–interface* Williams, 19??)

$$H = 0.13 \cdot \left(A_{acc}^{E} \right)^{0.4} \tag{16}$$

$$B = 1.29 \cdot \left(A_{acc}^{E} \right)^{0.6} \tag{17}$$

where:

H	=	**channel depth [m]**	$0.25\text{m} < \mathbf{H} < 20\text{m}$
B	=	**channel width [m]**	$0.5\text{m} < \mathbf{B} < 500\text{m}$
A_{acc}^{E}	=	**accumulated catchment area [km**^{2}**]**	

III Water Storage in Large Reservoirs

1. **Water balance equation for the reservoir**

$$S(t+\Delta t) = S(t) + Q_{in} \cdot \Delta t - Q_{out} \cdot \Delta t + N \cdot \Delta t \cdot A^R - EV \cdot \Delta t \cdot A^R - PERC \cdot \Delta t \quad (18)$$

where:

S	=	actual water volume stored in the reservoir ($0 \leq S \leq V_{max}$)
V_{max}	=	maximum water volume stored in the reservoir
Q_{in}	=	river flow into the reservoir
Q_{out}	=	outflow from the reservoir
N	=	precipitation
EV	=	lake evaporation (=potential evapotranspiration)
$PERC$	=	percolation
A^R	=	water surface of the reservoir

2. **Outflow from the reservoir is composed of controlled outflow and excess outflow:**

$$Q_{out} = Q_{contr} + Q_{spill} \quad (19)$$

where:

Q_{contr}	=	controlled, mamaged outflow from the reservoir (<u>water use</u>)
Q_{spill}	=	excess, unmamaged outflow (<u>over the spillway</u>)

first approach: A^R = S/50 m (S in m^2)
$N \cdot \Delta t \cdot A^R$: neglected
$PERC \cdot \Delta t$: neglected

HYMO: Model Variables

I Water Balance on the Hydrotope/Municipio - Scale

1. **Evapotranspiration:**
   - Net Radiation R_N
   - (cloudyness, surface albedo, ...)
   - air moisture saturation deficit $(e_s - e_a)$
   - air temperature, air humidity
   - wind velocity
   - θ_{act} (actual soil moisture)
   - θ_{FC} (soil moisture at field capacity)
   - θ_r (residual soil moisture)
2. **Soil Water Balance:**
   - N (precipitation)
   - q_o (surface runoff)
   - q_{gw} (percolation out of the topsoil)
   - q_l (lateral subsurface flow)
   - q_{deep} (deep groundwater recharge)
3. **Water budget of distributed ponds (small acudes):**
   - q_{acude}^{in} (surface flow into the pond)
   - q_{acude}^{out} (outflow from the pond)
   - $watuse_{acude}$ (water used from the acude (e.g. irrigation))
   - EV_{acude} (open water evaporation from the acude)
4. **Runoff into the major rivers (only one river stretch per municipio), composed of:**
   - q_{river} (runoff into the municipio's main river)
   - $(q_o)_l$ (surface runoff in the lowlands)
   - $(f_{intercep})_l$ (empirical factor for water collection in the acudes (lowlands))
   - $(q_{acude}^{out})_l$ (outflow from the ponds (lowlands))
   - $(q_l)_l$ (lateral subsurface flow (lowlands))

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   - Q_j^{in} (flow out of the municipio)
   - Q_j^{out} (flow into the municipio)

III Water Storage in Large Reservoirs

1. Water balance equation for the reservoir

   - S (actual water volume stored in the reservoir)
   - Q_{in} (river flow into the reservoir)
   - Q_{out} (outflow from the reservoir)
   - N (precipitation)
   - EV (lake evaporation (=potential evapotranspiration))
   - $PERC$ (percolation)
   - A^R (water surface of the reservoir)
   - Q_{contr} (controlled, mamaged outflow from the reservoir (water use))
   - Q_{spill} (excess, unmamaged outflow (over the spillway))

HYMO: Model Parameters

I Water Balance on the Hydrotope/Municipio - Scale

1. **Evapotranspiration:**
   - β_{hum} (reduction coefficient)
   - θ_{FC} (soil moisture at field capacity)
   - θ_r (residual soil moisture)
2. **Soil Water Balance:**
   - k_{sat} (saturated conductivity)
   - $f_{subfrac}$ (empirical factor)
3. **Water budget of distributed ponds (small acudes):**
   - S_{acude} (water volume in the pond)
   - $f_{intercep}$ (empirical factor for water collection in the acudes)
4. **Runoff into the major rivers (only one river stretch per municipio), composed of:**
   - $(f_{intercep})_l$ (empirical factor for water collection in the acudes (lowlands))

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1. The river network prescribes the water transfer system between all municipios Routing process through a municipio is approached with a linear response function:

   - k_{St} (roughness coefficient (Strickler coefficient $[m^{1/3}/s]$)
   - S_0 (channel slope [-])
   - B (channel width [m])
   - H (channel depth [m])
   - A^E_{acc} (accumulated catchment area [km^2])

III Water Storage in Large Reservoirs

1. Water balance equation for the reservoir

   - V_{max} (maximum water volume stored in the reservoir)
   - A^R (water surface of the reservoir)