4. *Infiltration from rivers and exfiltration from groundwater into rivers*:

If a grid cell is marked as a river cell (which is done by having valid entries in the river width grid, the river depth grid, and the leakage factor grid), exfiltration into the river bed can be calculated. Infiltration from rivers into groundwater can be calculated only if there is in addition an entry in a so called link grid, a grid containing the ID-number of the tributary which is sending it's water downstream to the actual cell. Thus, infiltration into groundwater is possible only at grid cells which are occupied by real routing channels, whereas exfiltration is possible at each grid cell which is marked as river. This scheme is based on the assumption that in smaller headwater subbasins usually the gradient of flow if directed from the groundwater to the rivers. Only in large stream valleys (which are usually routing channels) this gradient can be reversed if there are large amounts of external inflows from the upper areas.

The estimation of river width and river depth as well as the marking of routing channels is done in the preprocessing using the program TANALYS. It is also possible to use observed values by generating grids from any GIS-Coverage or from other bases.

The equations for estimating exfiltration and infiltration are relatively simple:

Exfiltration (which is the base flow), calculation has two steps:

a) calculation of exfiltration using the hydraulic gradient and the colmation (in- and exfiltration resistance) at the river bed:

$$q_{\mathrm{exf,pot}} = l_k \cdot \Delta H \cdot b_{\mathrm{rb}} / cs \qquad \textbf{(2.14.12)}$$

with
- $q_{exf,pot}$ maximum possible exfiltration (base flow) [m/s]
- l_k Leakage-factor (colmation resistance) [s^{-1}]
- ΔH positive difference between groundwater table and river bed
  $\Delta H = h_{GW} - h_{rb}$ (h_{GW}: groundwater table [m a.s.l.], h_{rb}: river bed [m a.s.l.])
- b_{rb} width of the river bed [m]
- cs grid cell size [m]

b) partitioning of $q_{exf,pot}$ to all affected soil layers: From each layer water can be extracted only until the pre-defined suction of 3.45 m is reached:

$$q_{exf,m} = \left(\Theta_m - \Theta_{\psi=3.45\mathrm{m}}\right) \cdot \Delta z_e / \Delta t$$

$$\text{for} \quad \mathrm{int}\left((h_{\mathrm{geo},0} - h_{GW})/\Delta z\right) \le m \le \mathrm{int}\left((h_{geo,0} - h_{\mathrm{rb}})/\Delta z\right) \qquad \textbf{(2.14.13)}$$

with
- $q_{exf,m}$ maximum possible exfiltration from layer m [m/s]
- m layer index, starting from the uppermost layer with contact to the groundwater down to the layer the river bed is within [-]
- Θ_m water content in layer m (usually saturation) [-]
- $\Theta_{\psi=3.45\,\mathrm{m}}$ water content at suction $\psi = 3.45$ m [-]
- $h_{geo,0}$ surface altitude [m a.s.l.]
- h_{GW} groundwater head [m a.s.l.]
- h_{rb} altitude of the river bed [m a.s.l.]
- Δz layer thickness [m]
- Δz_e effective layer thickness: If the layer is positioned completely between groundwater surface and river bed, then $\Delta z_e = \Delta z$ (overall layer thickness); if the groundwater table is positioned within layer m, then $\Delta z_e = h_{GW} - h_{geo,m}$; if the river bed is positioned within layer m, then $\Delta z_e = h_{geo,m-1} - h_{rb}$; if both, the groundwater table and the river bed are positioned within layer m, then $\Delta z_e = h_{GW} - h_{rb} = \Delta H$

If for the uppermost layer m the amount $q_{exf,m}$ is smaller than $q_{exf,pot}$, the remaining amount is taken from the next layer (or at least that part which can be taken from the next layer) and so on - as long as this next layers location is at least fractionally above the river bed. On the other side, if $q_{exf,pot}$ is smaller than $q_{exf,m}$, the amount taken from layer m is limited to $q_{exf,pot}$. The amounts taken from each layer are subsumed:

$$q_{\text{exf}} = \sum_m q_{exf\,,\,m} \qquad \textbf{(2.14.14)}$$

with q_{exf} amount of exfiltrated water

Infiltration: Like the estimation of exfiltration also the estimation of infiltration is done using equation (2.14.12). There are also two steps:

a) potential infiltration as given by the hydraulic gradient and by the transition resistance (colmation):

$$q_{\text{inf},pot} = l_k \cdot \Delta H \cdot b_{\text{rb}} / cs \qquad \textbf{(2.14.15)}$$

with $q_{inf,pot}$ maximum possible infiltration as given by the gradient [m/s]
l_k leakage-factor (transition resistance or colmation resistance) [s^{-1}]
ΔH positive difference between river bed altitude and groundwater table
$\Delta H = h_{rb} - h_{GW}$; if the groundwater table is below the river bed it holds:
$\Delta H = h_{rb} - hh_n$, whereas hh_n is the hydraulic head of the layer the river bed is positioned within
b_{rb} width of the river bed [m]
cs grid cells size [m]

b) In analogy to equation (2.14.13), the potential infiltration is filled into the soil layers starting with the layer the river bed is located in down to the groundwater table. The fillable porosity is the difference between the saturation water content and the actual water content as valid in the actual iteration step. Darcy's law is not necessarily considered, this means that there may be more infiltration than the hydraulic conductivity would allow. To limit the infiltration amount, the leakage factor should be reduced.

$$q_{\text{inf},m} = (\Theta_{sat} - \overline{\Theta_{m\,,\,iter}}) \Delta z / \Delta t \qquad \textbf{(2.14.16)}$$

with $q_{inf,m}$ maximum infiltration into the layer m as given by the fillable porosity [m/s]
$\overline{\Theta_{m,\,iter}}$ actual water content in the layer m as taken from the actual iteration step *iter* [-]

Like for exfiltration, also for infiltration a sub-summation is done during the filling of the layers:

$$q_{\text{inf}} = \sum_m q_{\text{inf},m} \qquad \textbf{(2.14.17)}$$

with q_{inf} infiltration amount which is already filled into empty layers [m/s]

If after the filling of all layers below the river bed this sum q_{inf} is still less than the potential infiltration $q_{inf,pot}$, then the layers in-between the river bed and the water table in the river are filled starting from the river bed up to the water table. If afterward the potential infiltration is still not completely filled into the soil, the real infiltration q_{inf} is limited to the actual accumulated value $\Sigma q_{inf,m}$. The total infiltration amount (in units of m^3) is stored in a table with entries for each routing channel. This table contains also the discharge within each routing channel as calculated by the routing-module (results from the previous time step). After calculating the infiltration the infiltration amount for the actual cell is subtracted from the discharge amount of the matching channel in the discharge table. If the infiltration after equations (2.14.15) to (2.14.17) is larger than the available amount of water in the channel, the infiltration is limited to that available amount in the channel. The channel is drying out.