Describing the routing structure in the control file:

Beside the usual routing of modeled discharges WaSiM offers also the possibility to consider external inflows as well as artificial (or natural) abstractions. A combination of an abstraction with an inflow is then an internal abstraction/inflow called a bypass. The impact of reservoir retention can be considered by applying an abstraction rule (a volume-runoff-table for each reservoir) or by applying a single linear storage approach to uncontrolled reservoirs.

<u>inflows, abstractions, bypasses:</u> Inflows and abstractions may be internal or external.
External abstractions will be subtracted from the modeled discharge, they are "losses" from the sight of the model, e.g. cooling water, irrigation water for external areas, abstractions for drinking water supply, but also losses by karst-phenomenon. Abstractions are defined as part of a routing description for a subbasin (see below). For each external abstraction a file is written containing the abstracted amount in units of m^3/s as well as the tracer concentrations of all actually modeled tracers (up to 9 tracers at the same time), each value in a column.

External inflows, on the other hand, are discharges which were not generated within the model itself, but which are nonetheless present in the reality, like waste water disposals or, more important, like natural inflows, which are not part of the model. This be happen, if only the lower part of basin should be modeled. Then, the discharges of the upper basin part have to be considered by an external inflow (read in from an external file together with all tracer concentrations, organized in columns).

Bypasses, which are combinations of (internal) abstractions and (internal) inflows, describe the artificial or natural transfer of water within the model domain outside of the routing channel system. An example are karst-phenomenons (losses in one subbasin and additional sources in another subbasin) but also artificial bypasses by hydro power stations often abstracting water from one subbasin and adding it to another subbasin. The difference between such bypasses and external inflows/abstractions is, that bypasses will not be written into or read from external files. A bypass can also not be constructed by a combination of external inflows and external abstractions, because the model connects only these inflows/abstractions which are marked with the keyword "intern". However, it is possible during subsequent model runs to define an external abstraction in the first model run which serves as an external inflow for another subbasin in the second model run. During the second model run the external abstraction should be defined, too (because of water balance in the lower basin areas), but it's important to use a different file name in order to avoid overriding of the abstraction file of the first model run. The advantage of such an approach is, that the inflow is well defined in the second model run and does not depend on any model parameter. Thus, it's also possible to use observed bypass-data.

<u>reservoirs:</u> If reservoirs or lakes have to be considered it is recommended to use the lake model – each lake is coded with it's unique ID in the lake grid. A routing description can deal with any number of storages/lakes, which are handled as a series of storages, but it is better to subdivide such basins into series of small subbasins. Abstractions will be taken from a reservoir, if there is one, also if there are multiple abstractions, they will be taken from the last (lowest) reservoir of that subbasin. Inflows are flowing into the uppermost (first) reservoir, if there are more than one reservoirs within the subbasin. Weirs or ground bolts should not be handled by reservoirs but by calibrating the hydraulic parameters of the channel, e.g. by calibrating single linear reservoir recession parameters for mean channel and flood plains.

<u>Routing descriptions:</u> For computing the discharge routing, hydraulic parameters of all channels as well as information about the drainage structure of the basin are needed. It is assumed, that the rivers are flowing into each other like in a tree-structure from the smallest branches to the trunk without branching in flow direction and without natural bypasses. This makes it possible to define an identifiable drainage structure for the basin, which could be computed subsequently link by link.

However, internal bypasses would destroy this scheme, so a compromise had to be found: the abstraction parts of internal bypasses are considered in the actual time step, but the inflow parts are considered in the next time step. This scheme avoids feed backs within the same time step. It is also physically reasonable to delay the inflow by one time step, because the physical realization of the bypass also needs a certain time. The drainage structure of the basin can be edited by hand using any common ASCII-editor. It is also possible to use the program TANALYS. This program generates a routing structure which is defined by the digital elevation model and by given pour-points or automatically extracted river mouths. However, TANALYS cannot handle abstractions and inflows, whether natural nor artificial ones, and it is also not able to consider reservoirs. These features has to be added by hand after the generation of the drainage structure. If the drainage structure does not match the reality then this may lead to unexpected results.

The routing can be done either by routing each tributary through a separate channel to the outlet where all routed discharges are summed up or by summing up all tributary discharges ate the begin of the routing and routing them through a single channel to the outlet. The first method is more appropriate if the basin subdivided according to a artificial gauge network, whereas the second method should be applied if the basin was subdivided following the natural river mouths, because the tributaries are united at the beginning of the routing channel. “Tanalys” can handle both situations. A routing description may contain any number of routing channels of both types (also mixed). All routed discharges and the runoff from the subbasin area itself are superposed at the outlet of the routing channels weighted by their relative areas on the actual subbasin total area (in-between-area of the actual subbasin plus areas of all tributary rivers which have to be routed through the actual subbasin). Each routing description may consist of any number of tributaries, external and internal inflows and abstractions, and reservoirs. The structure of the routing description is explained in the following example:

```
TG 9  (AE= 484.0, AErel=1.0)
from OL 10 (kh=0.4, kv=0.4, Bh=3.5,  Bv=20.0, Th=0.5, Mh=25.0, Mv=15.0, I=0.0128, L=10408.3, AE=3.75  )
 and OL 11 (kh=0.4, kv=0.4, Bh=7.0,  Bv=50.0, Th=1.0, Mh=25.0, Mv=15.0, I=0.0066, L=10838.5, AE=90.75 )
 and OL 12 (kh=0.4, kv=0.4, Bh=10.0, Bv=60.0, Th=1.4, Mh=27.0, Mv=15.0, I=0.0084, L=36339.6, AE=81.5  )
TG 5  (AE= 262.1, AErel=1.0)
from SUMTRIB 6&7 (kh=0.4, kv=0.4, Bh=6.0, Bv=30.0, Th=1.2, Mh=25.0, Mv=15.0, I=0.0195, L=10101.2, AE=133.75)
TG 4  (AE=1086.1, AErel=1.0)
from OL 5  (kh=0.3, kv=0.4, Bh=14.0, Bv=40.0, Th=2.5, Mh=30.0, Mv=20.0, I=0.0046, L=27005.3, AE=262.1 )
 and OL 8  (kh=0.4, kv=0.4, Bh=6.0,  Bv=50.0, Th=1.0, Mh=30.0, Mv=15.0, I=0.0090, L=26206.5, AE=16.5  )
 and OL 9  (kh=0.3, kv=0.4, Bh=15.0, Bv=60.0, Th=2.5, Mh=30.0, Mv=20.0, I=0.0037, L=26673.4, AE=488.1 )
TG 2  (AE= 208.8, AErel=1.0)
from OL 3  (kh=0.4, kv=0.4, Bh=7.0,  Bv=30.0, Th=0.9, Mh=25.0, Mv=15.0, I=0.0060, L=11952.7, AE=75.25 )
TG 13 (AE=1586.7, AErel=1.0)
from OL 2  (kh=0.3, kv=0.4, Bh=14.6, Bv=30.0, Th=2.0, Mh=40.0, Mv=15.0, I=0.0024, L=841.4,   AE=208.8 )
 and OL 4  (kh=0.3, kv=1.4, Bh=14.0, Bv=40.0, Th=3.0, Mh=45.0, Mv=15.0, I=0.0019, L=35000.0, AE=1086.1)
TG 1  (AE=1703.0, AErel=1.0)
from OL 13 (kh=0.3, kv=0.7, Bh=22.0, Bv=50.0, Th=4.5, Mh=45.0, Mv=15.0, I=0.0011, L=20289.9, AE=1586.7)
```

No inflows, abstractions, bypasses and reservoirs are contained in the above example (this is shown later). The first routing description (starting with the keyword “TG”) is defines the routing of the subbasins 10, 11 and 12 into the subbasin 9, where the separately routed discharges are superpose with the runoff from the subbasin 9 itself. Then, the routing is done for the subbasins 6 and 7, which are superposed already at the beginning of the routing channel (SUMTRIB = sum of tributaries). The routed sum of subbasins 6 and 7 is superposed with the subbasin-runoff of subbasin 5. Because the subbasins 5, 6 and 7 respectively 9, 10, 11 and 12 are independent of each other, the first routing description could have been also the second and vice versa. This is true also for the routing description of subbasin 3 into subbasin 2, which could appear anywhere before the subbasin 2 is routed itself. All these descriptions are responsible for the routing of head-water watersheds (STRAHLER-order 1) into larger (sub-)catchments of Strahler-order 2. The third description in the above example routes the discharges of the already routed subbasins 5 and 9 to the outlet of subbasin 4 and superposes them with the also routed discharge of subbasin 8 and with the internal runoff of subbasin 4. Applying this scheme, the routing is done according to the tree-structure of the catchment until the outlet of the entire basin is reached. If a model domain contains multiple basins, then its also possible to rout each basin separate using the above described commands.

Explanation of the key words in routing descriptions

- TG (German "Teilgebiet") subbasin; the subbasin for which the tributaries are routed and superposed at the subbasins outlet
- AE = xxxx real subbasin area, the real area includes the subbasin itself and all tributaries regardless if they are included in the model or not (see AErel)
- AErel=xxx relative subbasin area; Normally, the modeled area should be the entire catchment. But if a model application only considers the lower part of a basin, e.g. the lower Ganges river or the lower Mississippi, then the model will get the inflows from the upper basin parts as an external inflow. To remain consistent with the units of the modeled runoff it's required to tell the model, how large this upper area is (because runoff is routed as specific discharge). This is done by the relative fraction of the modeled basin parts of the total basin area.

  Example:

```
TG 9  (AE= 484.0, AErel=0.8264)
from OL 10 (kh=0.4, kv=0.4, Bh=3.5,  Bv=20.0, Th=0.5, Mh=25.0, Mv=15.0, I=0.0128, L=10408.3, AE=3.75  )
 and OL 11 (kh=0.4, kv=0.4, Bh=7.0,  Bv=50.0, Th=1.0, Mh=25.0, Mv=15.0, I=0.0066, L=10838.5, AE=90.75 )
 and ZL 1 (modus = extern geb12.dat 4 5, kh=0.4, kv=0.4, Bh=10.0, Bv=60.0, Th=1.4, Mh=27.0, Mv=15.0, I=0.0084,
L=36339.6, AE=84.0 )
```

  If the subbasin 12 in the above example would not be included into the model domain, then the real area of subbasin 9 remains at 484 km^2, but the modeled area for subbasin 9 is only 400 km^2. So the relative fraction of the modeled on the total basin area is 0.8264. The routed specific discharges has to be scaled by this factor in order to be comparable to observed runoffs for subbasin 9. The inflow from subbasin 12 must be read in as an external inflow. These external inflows are given in m^3/s and they need the same parameters than the regular tributaries, because they may be natural inflows (like in the example) which are routed through real channels. The Subbasin area of such external inflows must be given only for calculating an internal runoff table.
- OL xx Zone code of the tributary to be routed (according to the zone grid for the soil model)
- SUMTRIB a&b&c… Codes of tributaries a, b, c a.s.o. which are connected by "&" (no external or internal inflows!); the discharges of all listed tributaries are superposed at the beginning of the routing channel and routed in a single channel. For each routing description (i.e. for each "TG") any number of OL's, SUMTRIB's and ZL's (see below) may be defined.
- ZL xx external or internal inflows (explanations see below)
- kh, kv Storage coefficients for single linear reservoir considering retention in a channel, units in hours, kh for the mean channel, kv for the flood plains
- Bh, Bv width of the mean channel (Bh) and the flood plains (Bv) [m]
- Th depth of the mean channel [m]; the depth of the flood plain is theoretically unlimited
- Mh, Mv Manning-Strickler-roughness parameters for mean channel (Mh) and flood plains [$m^{1/3}$/s]
- I mean slope angle along the routing channel [1/1]
- L length of the routing channel [m]
- AE (real) subbasin area if the tributary [km^2]

The input of the subbasin area AE in the first row of a routing description is required in order to be able to convert inflows and outflows as well as reservoir extractions from m^3/s into mm/time step and vice versa. It's also important to make sure that the weighted superposition of the tributaries discharges works correctly. On the other hand, the input of the subbasin area of the tributaries is only of importance for the generation of discharge-flowtime-tables at the beginning of the model run. These areas should be in such a range that the expected discharges (in mm/h) are within the discharge-flowtime-tables range as given in the control file. If these areas are much too small, the flow times for floods will be too large, because the runoff-flowtime-table will have no entries for such high specific discharges following from too small basins. The same reason is true for the input of a subbasin area for external or internal inflows. The area is needed only for generating the discharge-flowtime-table. For modeled real tributaries WaSiM checks the given areas with the areas taken from the zone grid and changes the values to the latter, if differences occur. This is not possible for inflows, so here a realistic input is required. If a inflow is an observed runoff of a subbasin which is not included in the model, this area can easily be get from the DEM or from the literature. For artificial inflows the "area" should be in a reasonable relation to the other hydraulic parameters of the channel. If, for instance, the channel has a width of 3.5 m, a depth of 0.5 m, a slope of 0.01 and Manning-Strickler-value of 25 $m^{1/3}/s$, a flow velocity of 1.332 m/s would be valid for a full channel according to a discharge of 2.33 m^3/s. If the expected inflows vary between e.g. 0.2 and 2 m^3/s, the Area could be chosen between 5 and 30 km^2, thus resulting in specific discharges between 6.67 and 66.7 $l/s/km^2$ (at 30 km^2) respectively between 40 and 400 $l/s/km^2$ (at 5 km^2). If the range for the discharge-flowtime-table is given as e.g. 5 $l/s/km^2$ for the minimum and 1200 $l/s/km^2$ for the maximum considered specific discharge, then all possible inflows are routed with a velocity which can be found within the table (what area is given is not important as long as the range of resulting specific discharges is in-between the minimum and maximum values, the flow times are identical for all areas within the proper range because the table entries are only shifted what is compensated by the conversion of discharge from m^3/s into $l/s/km^2$ using different areas).