



**Work package 4, Deliverable D 411**

**Report on JAMS modelling at the scale:  
SMART trans-boundary groundwater model**

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The aim was to develop a hydrological model to simulate groundwater recharge at the regional scale of the SMART-trans-boundary model. The applied J2000g software allows a physical-based modelling of the water budget of regional catchment areas.

#### METHOD OF HYDROLOGICAL MODEL J2000G

The input data for JAMS are spatially organized in hydrological response units (HRU), which lead to a spatially discriminated output. The hydrological model J2000g is a rainfall-runoff model to estimate spatially distributed hydrological water balance components (Krause and Hanisch, 2009; Krause et al. 2010). J2000g is one of the modules, which are available from the JAVA framework system JAMS (Jena Adaptable Modelling System) (Kralisch and Krause, 2006).

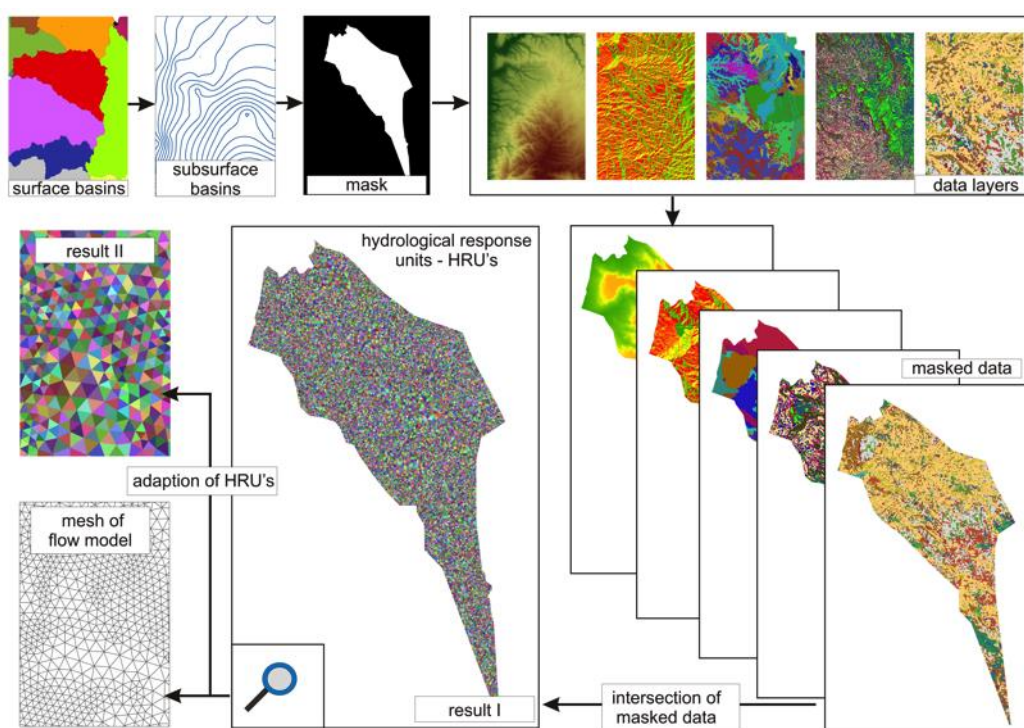


Figure 1: Different input parameters of the soil moisture model J2000g.

The model requires daily or monthly meteorological input data (rainfall, temperature, sunshine duration, relative humidity, wind speed) and spatially distributed information on topography, soil types and land-cover to describe the physio-geographical conditions of the study area. The catchment is subdivided into hydrologically similar behaving entities, so called Hydrological Response Units (HRU). HRUs are delineated by GIS overlay analysis of the spatially distributed input information. Based on GIS-derived information, each HRU is described by its elevation, slope, aspect, land-cover and soil type (Figure 1). Beside the simulation of hydrological

processes, which control the runoff formation and concentration in the upper meso - and macro scale, the model contains routines to regionalize discrete punctual climate- and precipitation data. Additionally, the calculation of real crop evaporation is integrated in the model and allows a spatial distributed calculation of evapotranspiration of different land-cover types.

For each HRU and each time step, water balance components i.e. evaporation are calculated according to the climatological input data, which are regionalized by spatial interpolation using inverse-distance-weighting and optional elevation correction. A detailed description of the hydrological model is given in Kralisch and Krause (2006) and Rödiger et al. (2013).

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#### CONCEPTION MODEL OF THE TRANSBOUNDARY MODEL

The size of the SMART trans-boundary model defines the working frame of the hydrological model J2000g. In respect to deliverable D601, considering the main groundwater basin along the western and eastern side of the Lower Jordan Valley, respectively, set up the extension of the trans-boundary model. The main groundwater aquifers of the region are on the western side the Judea Group Aquifers and on the Jordanian side the A7-B2 aquifer.

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#### MERGING OF JAMS ATTRIBUTES

The mentioned input data for JAMS are spatially organized in hydrological response units (HRU), which lead to a spatially discriminated output. The HRU mesh builds a raster of defined scale, and therefore, it is necessary to up- or downscale the input data, e.g. satellite scenes, aerial photographs and field data (Figure 2). To simplify the linkage between the SMART trans-boundary groundwater model and the hydrological model JAMS, the used HRU mesh is derived from the finite element grid of the numerical groundwater flow model (Fig. 2 and 3). This mesh defines the resolution for all input parameters of J2000g. Because the mentioned input data of J2000g, particularly the characteristics of the relief, the specific soil and the vegetation parameters are spatially organised in HRUs. In the present case the hydrological response units are conform to the elements of the trans-boundary model. The descriptions of the used JAMS attributes are given in the report to deliverable 401.

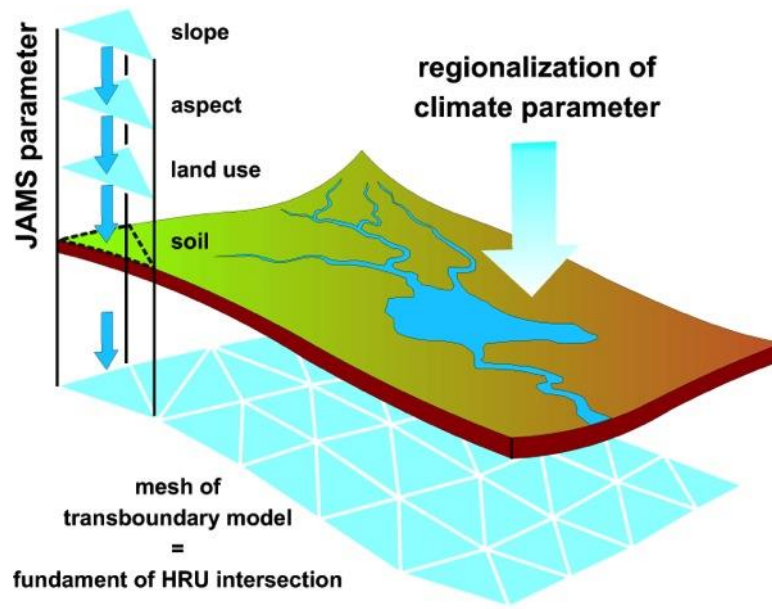
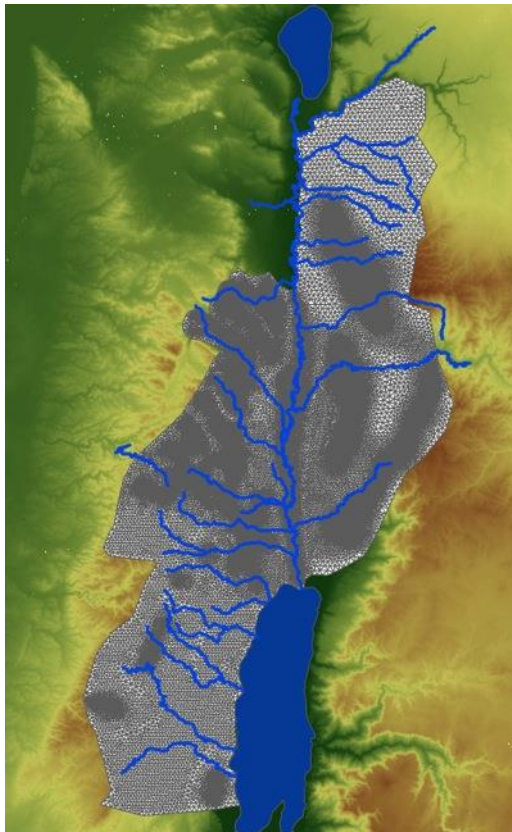


*Fig. 2. The concept of HRU derivation*



The following intersections of the input parameters were handled in GIS. In the first step the originally mesh of the trans-boundary mesh was complemented along the main Wadi courses. This step is necessary, because the Wadi geometry mainly controls the infiltration processes in the study area. The Wadis were defined by their individual width and length (Fig. 4). Afterwards the Wadi geometry was intersected with the mesh of the trans-boundary model and a ground mesh of the hydrological response units was created (Fig. 2). The intersections of additionally needed J2000g attributes (slope, altitude, aspect, land uses, soil) are related to this mesh. The land-use intersection is shown in Figure 5 as an example for the intersection processes of each parameter.

*Fig. 3: The dimension of the trans boundary model along the Lower Jordan Valley*

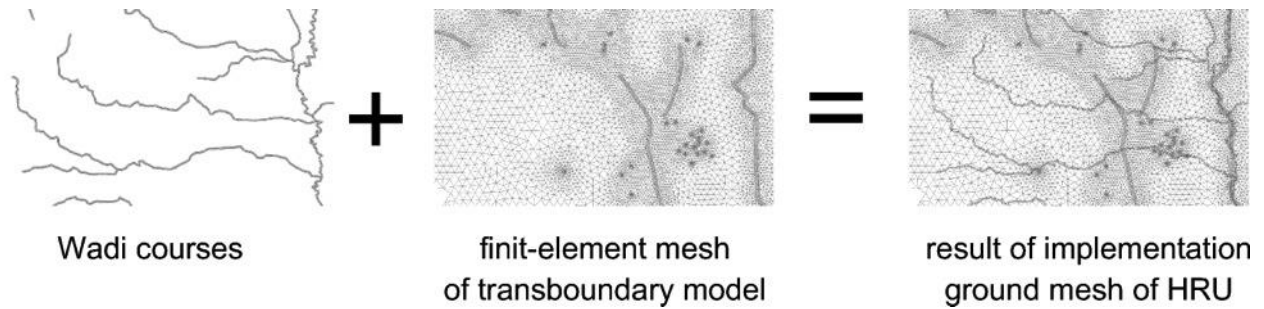


*Fig. 4: Implementation of Wadi courses in finite-element mesh of the trans-boundary model. The result is the basic HRU mesh for the further intersection processes.*

On the base of the HRU ground mesh an oversimplification is given on same position after the intersection but the context of the input parameters is conserved.

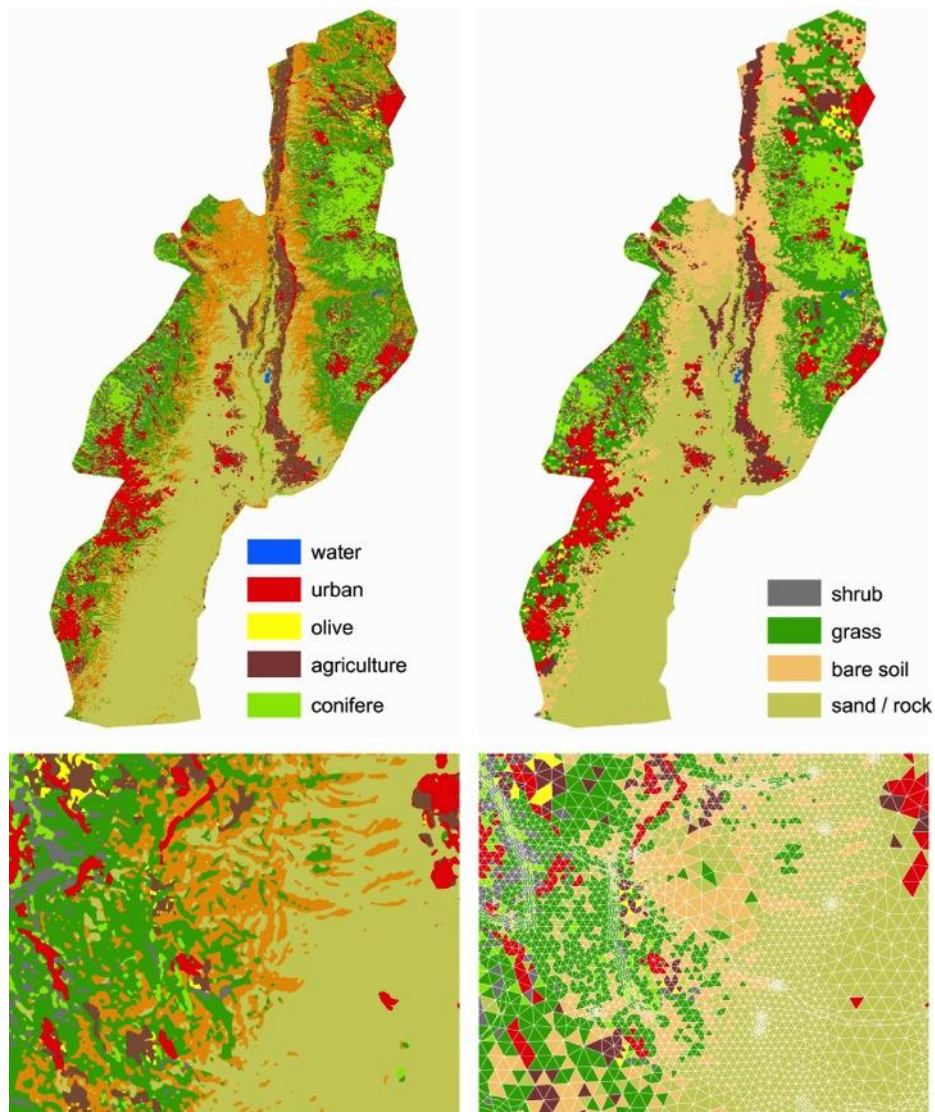


*Fig. 5: The finished intersection between HRU ground mesh and the land use parameter (left site original data, right site intersected data).*

To apply J2000g, climatic information with spatially distributed parameters describing the catchment are needed. Therefore, installing own tipping buckets completed already existing precipitation and climate stations in Israel and Jordan. The additional tipping buckets were installed in the West bank, the Ajloun and within the Fuheis demonstration site in Jordan during December 2011. The tipping buckets are automatically uploading their data via GPRS to the webpage of Pessl instruments (fieldclimate) (Fig. 6).



Fig. 6: Network of tipping buckets of the UFZ (blue dots existing rain and climate stations; red dots future station (installation spring 2012)).

The installation of the tipping buckets on the western side was done in close cooperation between MEKOROT Co. Ltd., the Hydrological Survey of Israel and the UFZ. The cooperation additionally opened the way to share data. Consequently, we got a much better climate data pool for the SMART project area. Due to the option of DASIY (WP2), we were able to use climatic data, generated by the SMART community (e.g. by Ministry of Water and Irrigation, Jordan) to close data gaps. As a result 102 precipitation stations were available and were used

to set up the J2000g model. The integration of all existing rain and climate stations in the region provides very reliable information of distribution of precipitation along the western and eastern part of the Lower Jordan Valley (Fig. 7). The results of regionalisation processing in J2000g of punctual data of 102 precipitation stations and the annual precipitation map for the region are shown in Figure 7. It is observable that the interpolations of the 102 stations in J2000g lead to a well regionalisation and both maps represent each other. However, areas of strong divergence do exist, particularly in the southern part of the Lower Jordan Valley. Possible reasons for the discrepancies are non-continuous precipitation data during the modelled period. The precipitation map shows a good reproduction of the rainfall gradient, with higher values >700 mm/yr at the elevated mountain areas in both flanks and low values of about 100 mm/yr inside the Jordan Valley.

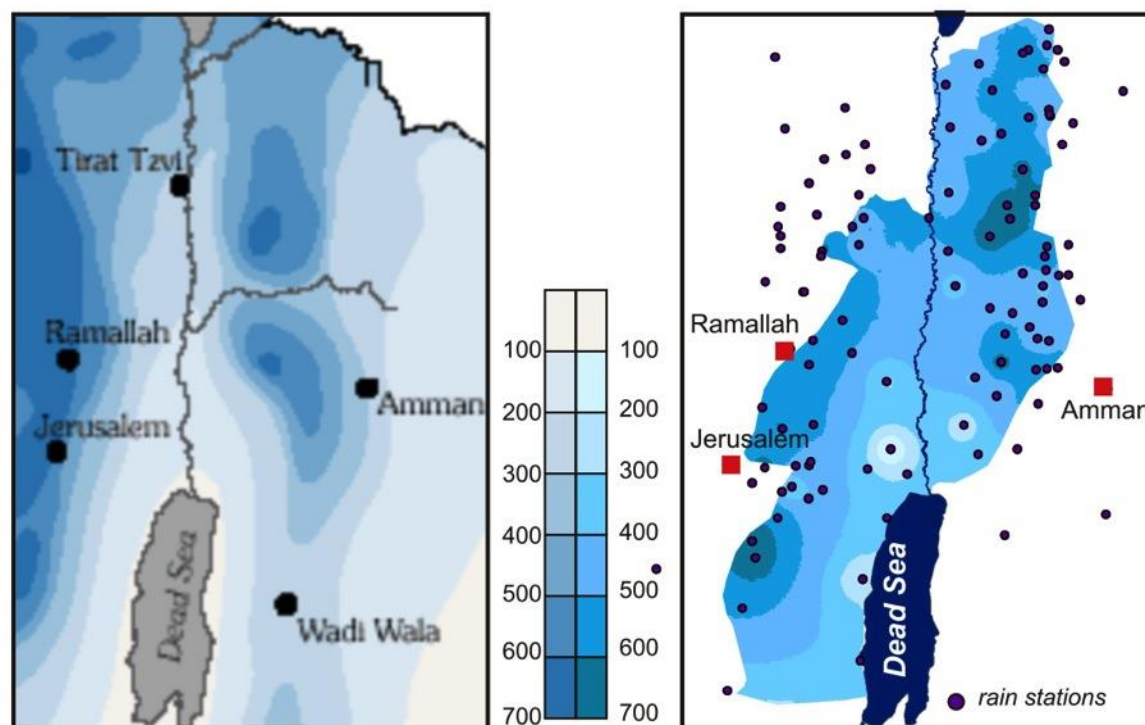


*Fig. 7: Comparison between annual and regionalized precipitation by J2000g for the model area*

Parameterisations of physical soil properties based on the soil map classification of Israel (Dan et al. 1976; Ravikovitch 1969) and National Soil Map of Jordan (Ministry of Agriculture, Jordan, 1994) (Fig. 8). 14 different soil units (soil types) were classified in the project area. To unify the information of the different soil maps into one soil map (Fig. 2) was a challenge. The average soil depth and field capacity of each soil unit was estimated by results of field trips and from literature values (Bashan et al. 1995, Dan 1980, Dan et al. 1983, Ministry of Agriculture Jordan 1994, Mimi et al. 2009, Singer 2007, Smith et al. 1985). The USDA taxonomy 1975 of National

Soil Map of Jordan hindered the parameterisation of the map. Therefore a diploma student modified the soil map for the Wadi Zarqa catchment (Jordan) and used a morphological approach to generate a better soil map (Schulz 2011). During the diploma thesis, the approach was successfully implemented into J2000g. It is to consider that the approach should general used on the Jordanian site instead of the National Soil Map of Jordan.

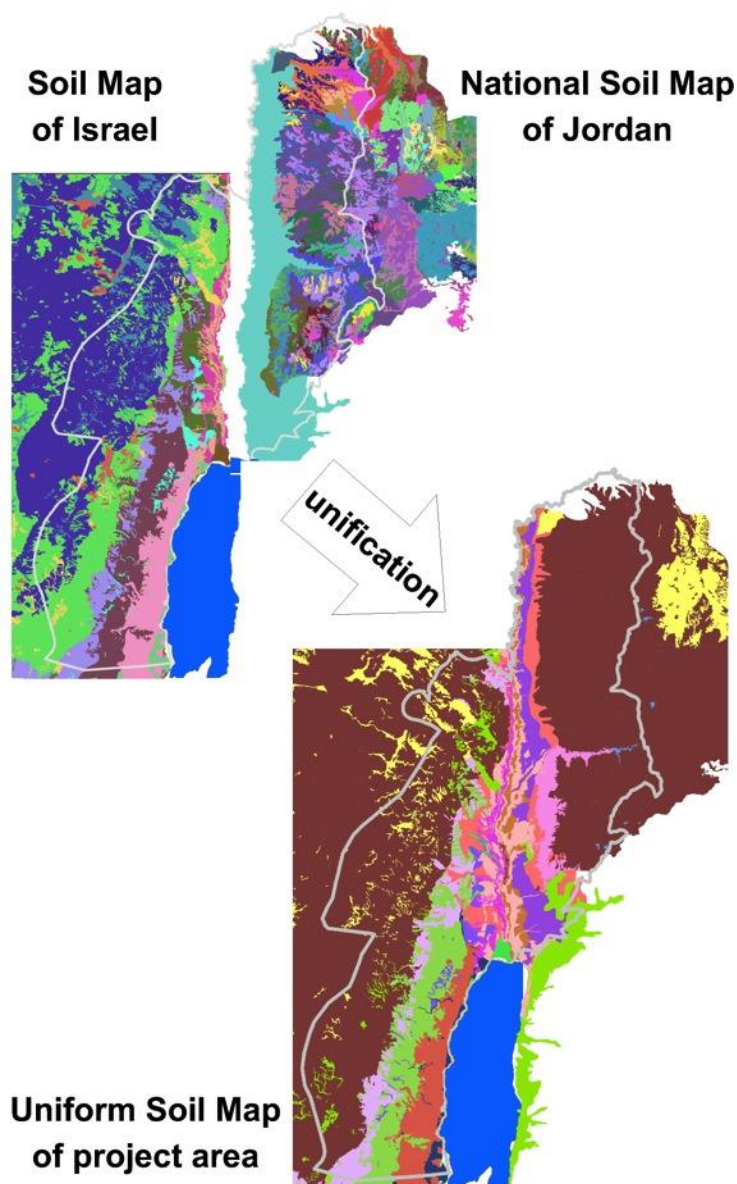


*Figure 8: Unification of the different soil maps of Israel and Jordan*

#### MODEL SETUP OF J2000G

To run the hydrological model, monthly data series of precipitation, relative humidity, relative sunshine duration, temperature and wind speed were available for the period November 1977 to November 2010.

Based on trans-boundary mesh, spatially distributed parameters describing the HRU were derived from GIS along with a-priori values from literature.

Topographical parameters (slope, aspect and elevation) were obtained from a digital elevation model (DEM 25 x 25 m).

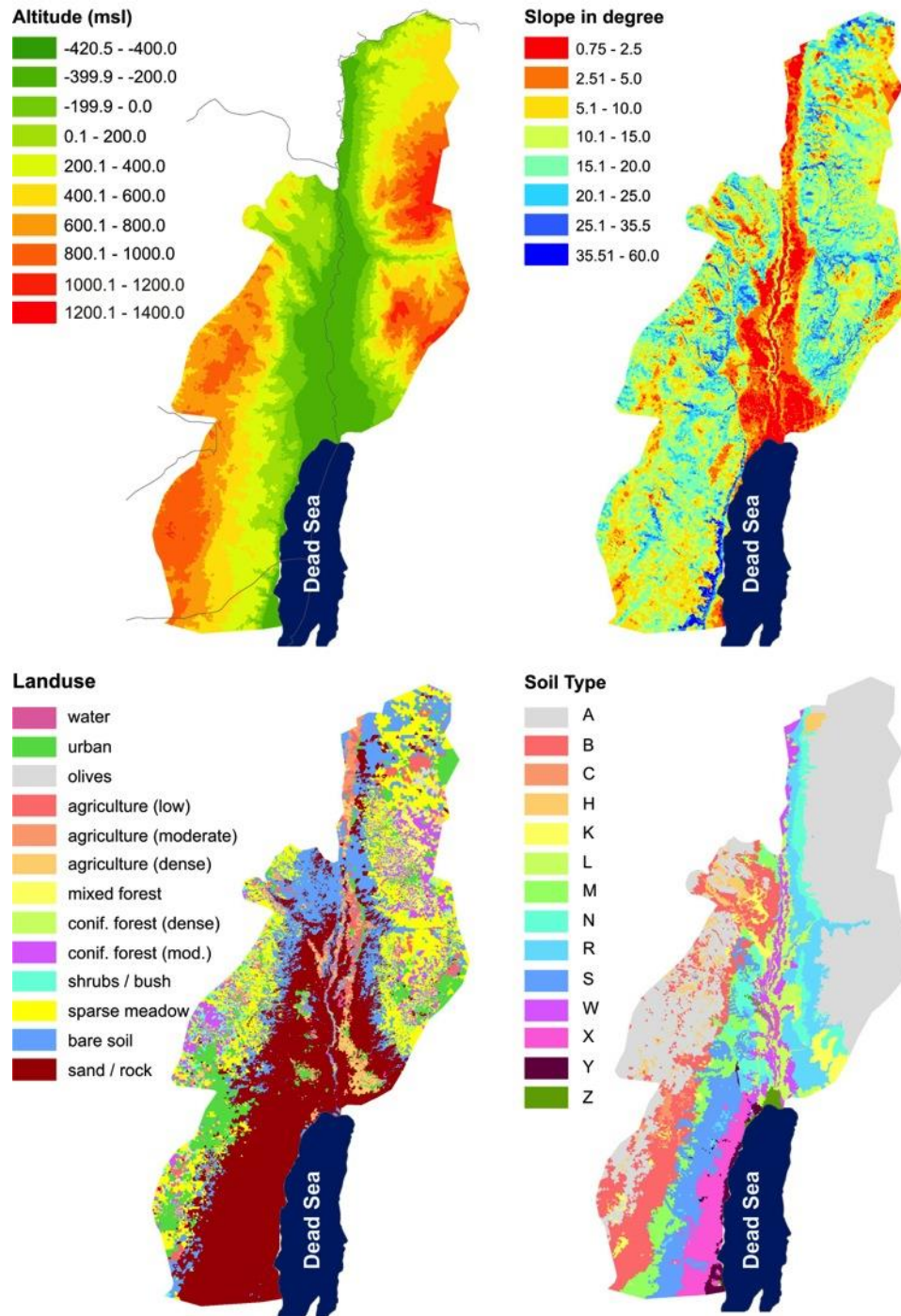


Fig. 9: Model setup parameter of the HRU mesh by J2000g

According to Tilch et al. (2002), the slopes (s) and their according surface ratios (A) were classified into four groups: (i)  $0^\circ < s \leq 5^\circ$ ,  $A=0.18$ ; (ii)  $5^\circ < s \leq 15^\circ$ ,  $A=0.47$ ; (iii)  $15^\circ < s \leq 30^\circ$ ,  $A=0.34$  and (iv)  $30^\circ < s \leq 90^\circ$ ,  $A=0.01$ . The area aspects and their according A were classified into eight classes by  $45^\circ$  segments and one class by -1: NNE,  $A=0.15$ ; ENE,  $A=0.12$ ; ESE,  $A=0.13$ ; SSE,  $A=0.12$ ; SSW,  $A=0.15$ ; WSW,  $A=0.13$ ; WNW,  $A=0.13$ ; NNW,  $A=0.03$ ; and -1,  $A=0.02$ ).

Land-cover was classified by using an ASTER image from May 2000. Ground-truth data were obtained from different field campaigns during 2007 and 2009. According to the dominant plant types (Figure 9), 10 major and 13 sub classes were distinguished. Vegetation specific parameters such as leaf area index or stomata resistance were estimated from literature values (Wilson and Henderson-Sellers, 1985; Dorman and Sellers, 1989; Rhizopoulos and Mitrakos, 1990; Acherar and Rambal, 1992; Körner, 1994; Schulze et al., 1994; Kergoat, 1998; Baldocchi et al., 2004; Niinemets et al., 2005) shown in Table 1.

*Tab. 1: Land cover parameters of the hydrological simulation*

| Land cover / subclasses                                 | Area % | Surface resistance per class land cover (s/m)* | Leaf Area Index ( $\text{m}^2/\text{m}^2$ )* |
|---------------------------------------------------------|--------|------------------------------------------------|----------------------------------------------|
| Impervious areas                                        | 9      | 10                                             | -                                            |
| Agriculture (low, moderate, dense)                      | 8      | 95 - 1,000                                     | 0 - 1                                        |
| Water                                                   | 0      | 10                                             | -                                            |
| Sand/Rocks                                              | 32     | 70                                             | -                                            |
| Shrubs                                                  | 3      | 102 - 323                                      | 4 - 5                                        |
| Forest (coniferous + deciduous)                         | 8      | 143 - 667                                      | 4 - 7                                        |
| Rangeland (grass / hill grass (very light) / bare soil) | 36     | 70 – 1,000                                     | 0 – 1.6                                      |
| Olive orchards                                          | 4      | 141 – 1,000                                    | 3                                            |

\* data taken from literature values.

Parameterisations of soil physical properties based on the soil map classification of Israel (Dan et al. 1976; Ravikovitch 1969) and National Soil Map of Jordan (Ministry of Agriculture, Jordan, 1994) (Fig. 9). 14 main soil classes and 77 subclasses were digitized (Figure 9). These classes can be distinguished by grain size, porosities, field capacities and thickness.

The thickness of the different soil types range between 30 and 200 cm. The total field capacities vary between 42 and 743 mm.

The maximum percolation capacities for the geological units were derived from Berndtsson and Larson (1987). As stated above, to generate the HRU, all input parameters were spatially integrated, which resulted in a spatially discriminated mesh of about 92,500 HRU-cells.

## CALIBRATION AND VALIDATION

Because of the insufficient runoff data measurements, the classical runoff calibration and validation by confronting the simulated with the measured data was not possible. Therefore, a nested multi-response calibration strategy was used to reduce the scarce data situation.

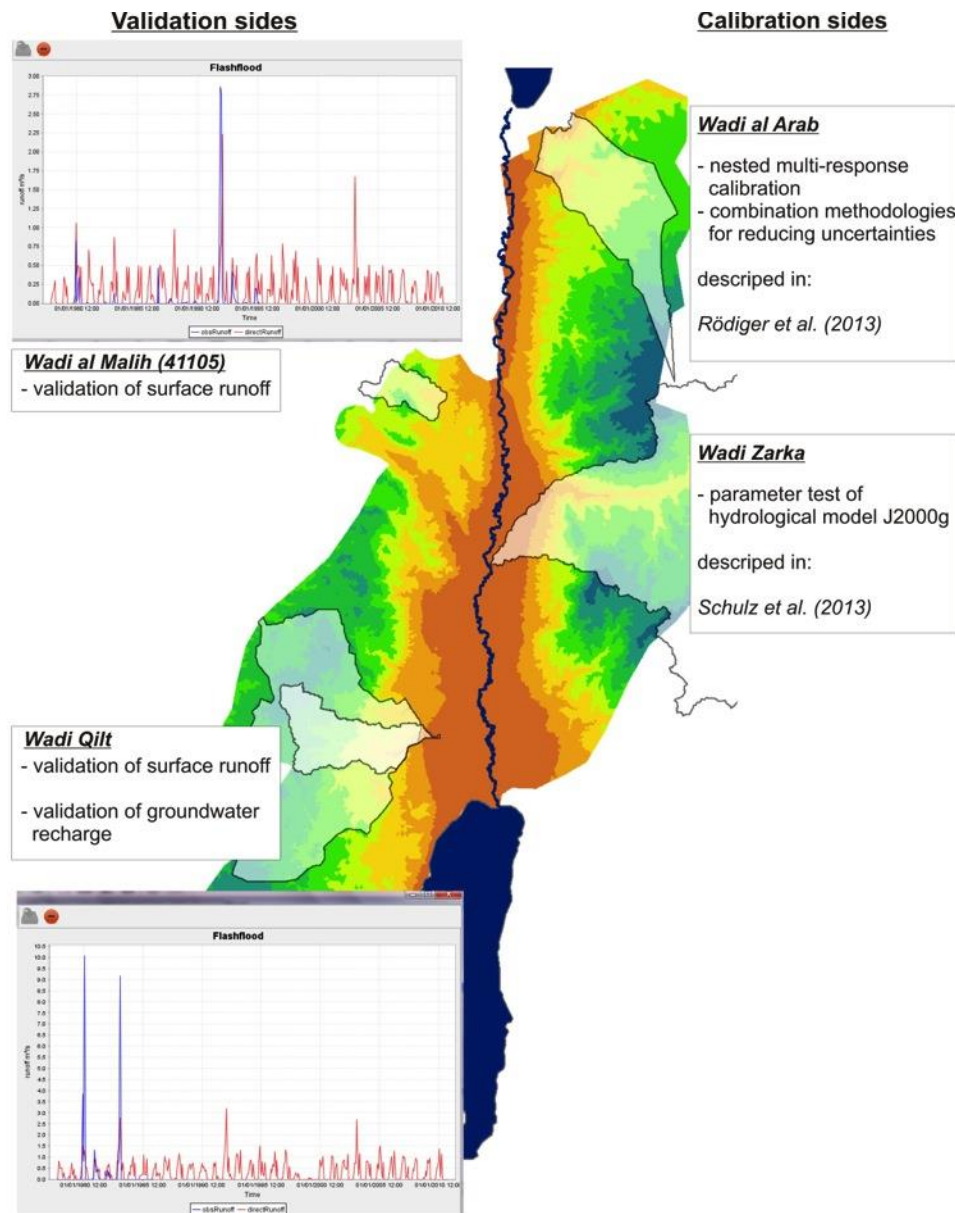


Fig. 10: Calibration and validation strategies in different catchments

The multi-response calibration is based on multivariable measurements (flash flood, groundwater level, spring discharge, groundwater chemistry etc.). Dependent on the available data, chloride mass balance-, water table fluctuation- and gauged spring discharge-methods are used to produce calibration and validation data on different local areas (Fig. 10).

For calibration of the model, the different calibration coefficients of the hydrological model have been adapted according to the results of the above stated 3 independent methods. The model parameter test and the calibration process started on the Jordanian side in Wadi Zarka and Wadi al Arab. The presented model approach of J2000g has the ability to reflect the major hydrological processes of both catchments, including the simulation of a double porosity aquifer system. The different strategies are described in Schulz et al. (2013) and Rödiger et al. (2013). The identified calibration parameters were directly transferred to the western side.

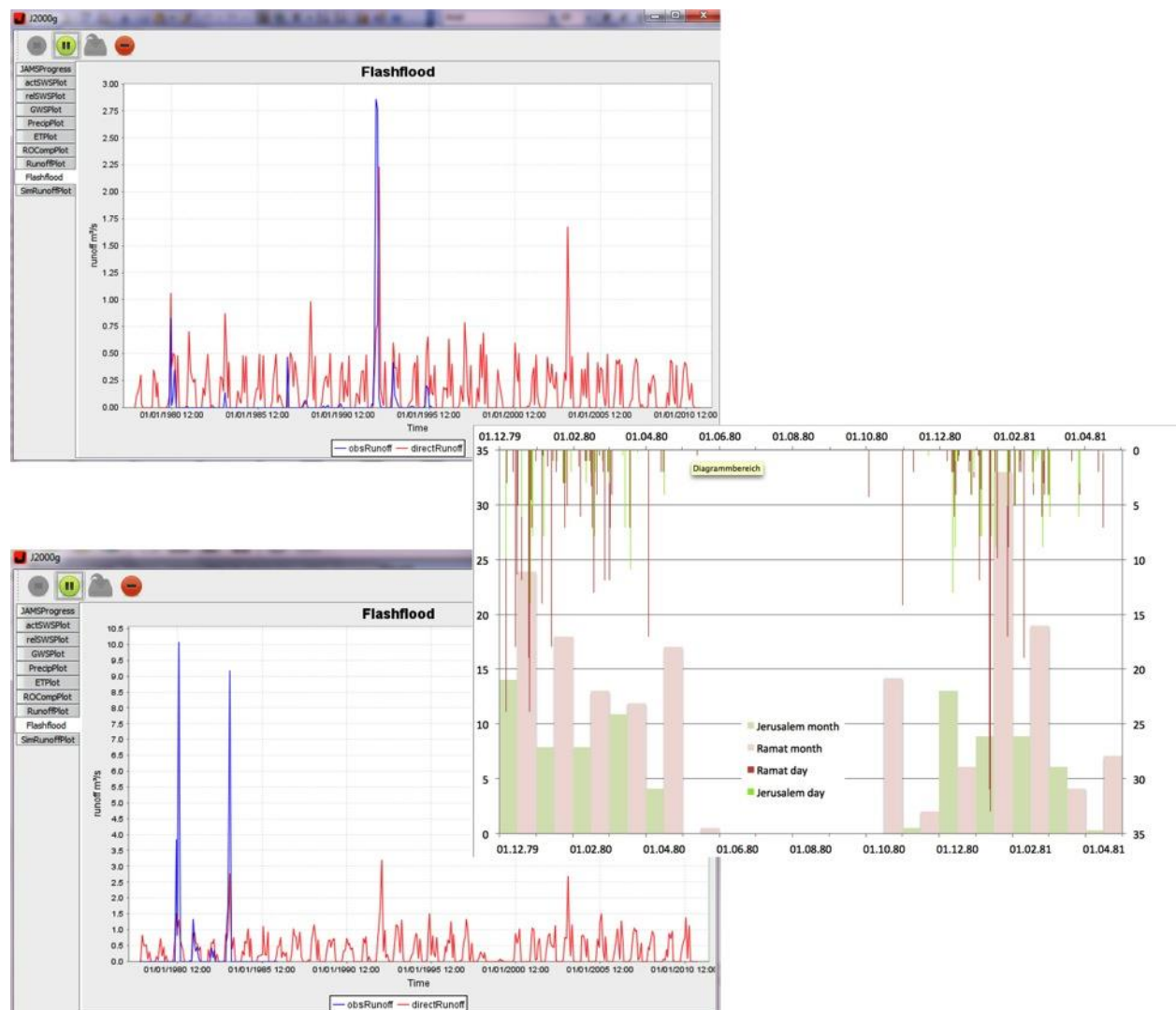


Fig. 11: Correlation results of surface runoff for the validation areas Wadi al Malih and Wadi Qilt

The validation on the western side was done according to simulation of surface runoff and groundwater recharge in Wadi al Malih and Wadi Qilt, Westbank. In both catchments the observed surface runoff events typically react on the heavy precipitation events by a quick response and with a high flow rate. These flash floods predominantly consist of direct surface runoff. Therefore the observed and the simulated surface runoff by J2000g were compared. In Figure 11 it is visible that the results correlate well, but the best fit results in Wadi Qilt (lower flash flood picture). The circumstance are linked by the model time resolution in month and mainly by the precipitation frequency within the different catchments. The northern part of the western catchment side is characterized by a multitude of precipitation events within a month. In contrast the southern part is affected by single heavy precipitation events during a short time (rainfall diagram in Figure 11). In regarding to the available precipitation data (mainly information in month) the less daily information are summarized per month. During that step a falsification of the rain values was generated because the hydrological model is not able more to distinguish between rain duration and frequencies. That case lead to an overestimation of the precipitation events, which affect also the simulation of the surface runoff and groundwater recharge. In the upper picture in Figure 11 is detectable, that partly flash floods events are computed while they are not measured. That phenomenon reflects the upper limit of time-steps for calculation of the hydrological model. In fact to that results future models should have a higher temporally resolution.

Additionally the dimension of the simulated groundwater recharge is used for the validation of the trans-boundary model. The produced results correlates well with the results of groundwater recharge by CMB and GSD (Rödiger and Siebert, 2009). In the combination of all facts it act to the assumption that the model reflects the main hydrological process well and can be used for the quantification of the groundwater recharge. The simulation results are summarized in table 2.

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## MODELING RESULTS

The model simulation period was set up for a time series from 1977-2010. The presented model approach of J2000g has the ability to reflect the major hydrological processes of the catchment. The main simulation results are summarized in table 2. Figure 12 shows the final regionalized and simulated annual groundwater recharge, the surface runoff, the potential and real (actual) evapotranspiration derived for the individual HRUs for the modelling period. The recharge plot illustrates the consistent relation between precipitation and groundwater recharge in the study area. The groundwater recharge fluctuates similar to precipitation. High values of around 250 mm/yr of groundwater recharge are restricted to the elevated parts of the model area.

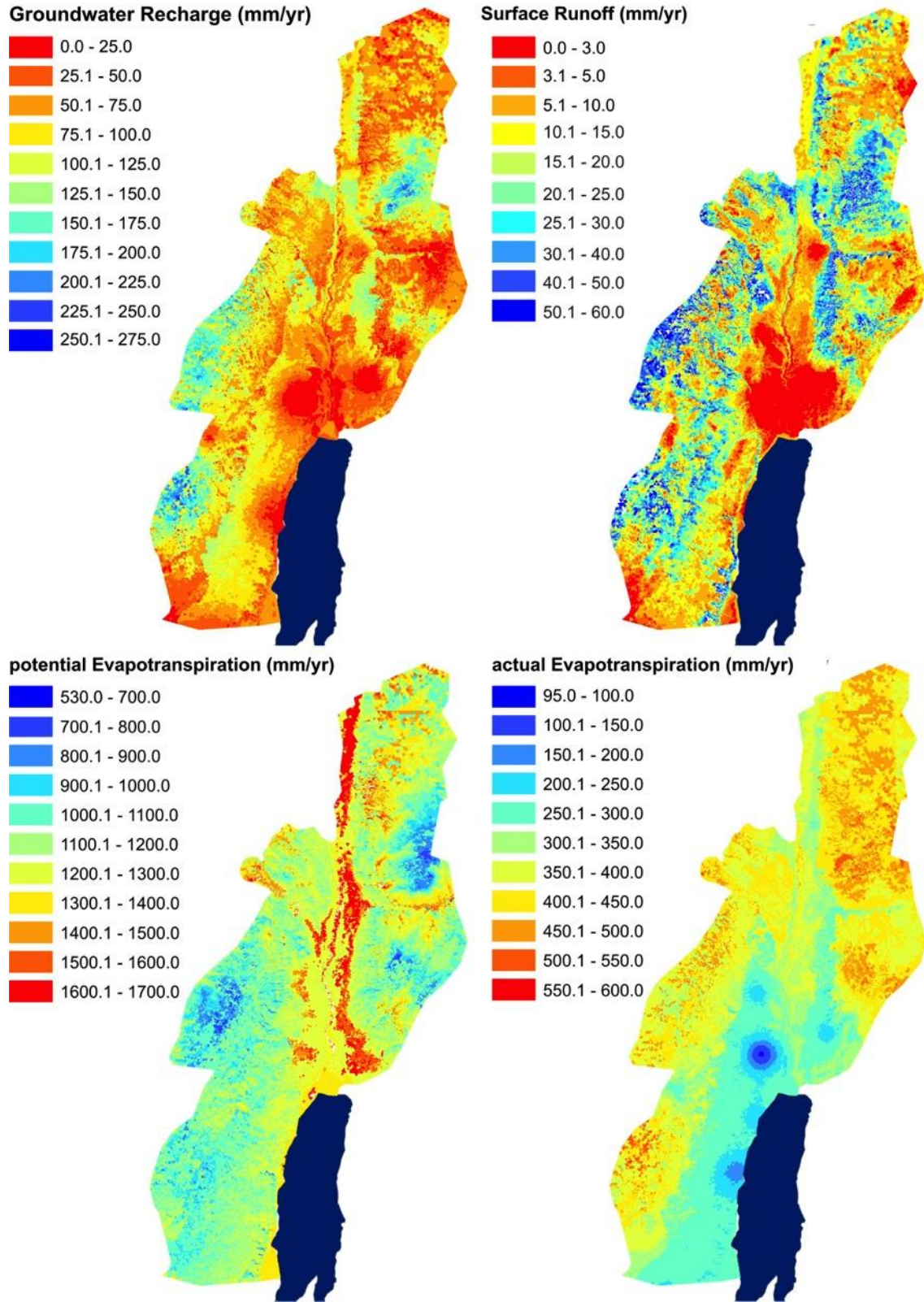


Fig. 12: Regionalized simulated groundwater recharge, direct runoff, actual and potential evaporation by J2000g for the trans boundary catchment.

Tab. 2: Results of water budget simulated by J2000g in depend on the catchment scale

| Catchment<br>(km <sup>2</sup> ) | Precipitation<br>(P) (mm/yr) | Actual Evaporation<br>(E) (mm/yr) | GW recharge (R)<br>(mm/yr) | Direct runoff (RD)<br>(mm/yr) |
|---------------------------------|------------------------------|-----------------------------------|----------------------------|-------------------------------|
| Total (6,006)                   | 443                          | 352                               | 75                         | 16                            |
| East (2,701)                    | 472                          | 382                               | 72                         | 18                            |
| West (3,305)                    | 450                          | 349                               | 80                         | 21                            |

Contrastingly, in the Lower Jordan Valley the groundwater recharge decreases to less than 25 mm/yr. All other simulation results (surface runoff, actual and potential evapotranspiration) reflect also the connection to the precipitation. General a separation between the western and eastern mountain areas and the Lower Jordan valley is visible.

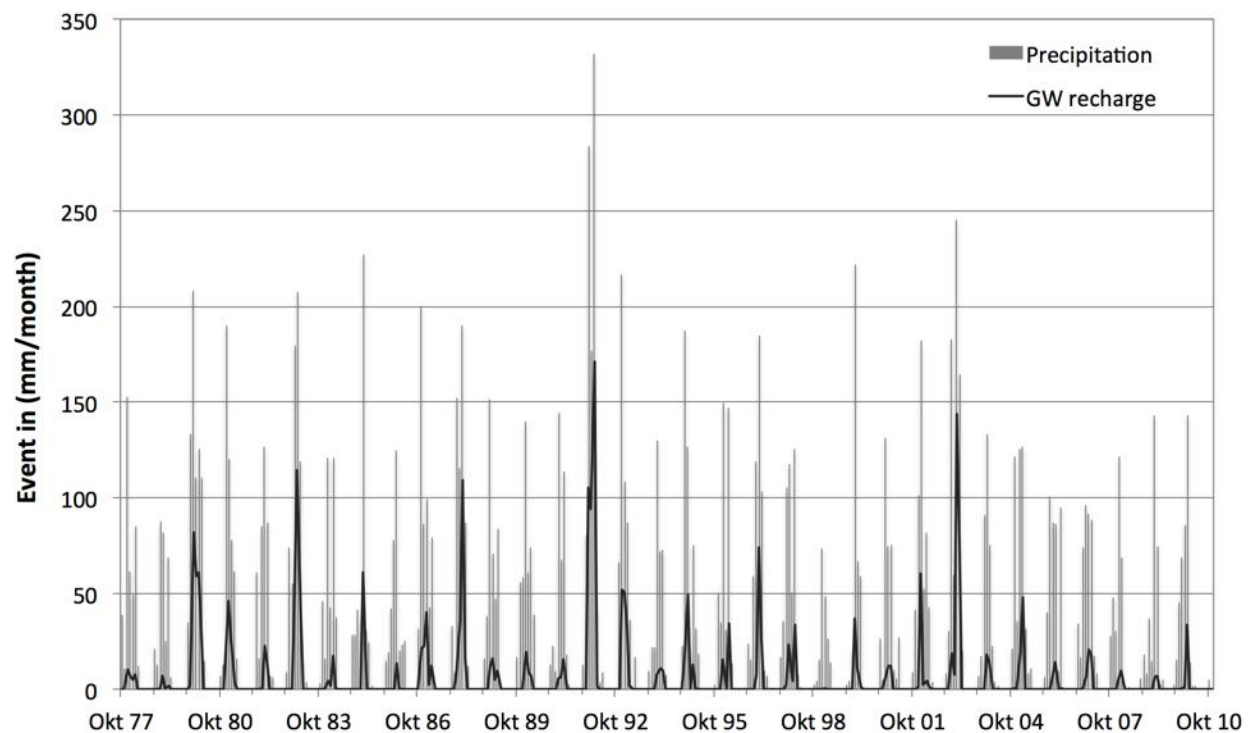


Fig. 13: Final simulated precipitation (grey column) and groundwater recharge (black line) by J2000g for the trans boundary catchment (Year 1977 – 2010)

The final simulated mean groundwater recharge for the entire catchment is shown in Figure 13. The Figure illustrates the rhythm of precipitation only during the wet and very seldom during the dry seasons in the period 1977-2010. It is detectable that the years 1979 and 1999 were the driest years, whereas the years 1986, 1992, and 2003 were wettest. It is shown that the moment

of groundwater recharge (black line) is strongly related to the moment of precipitation. The outcomes reveal only precipitation amounts exceeding 100 mm/month are generating groundwater recharge.

The spatial setting of the hydrological model allows us to specify groundwater recharge even for small locations within the model area. Hence, these simulation results are the best available input-function to toughen up the SMART trans-boundary model to become transient.

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