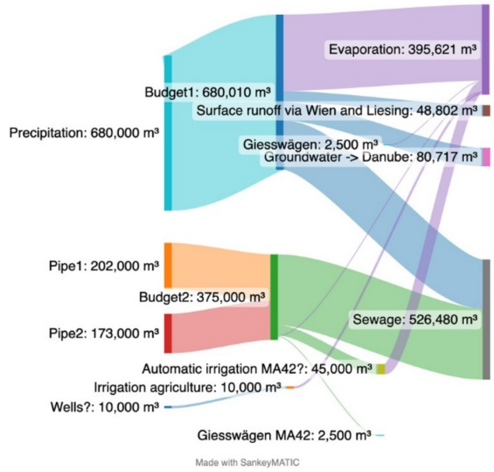
Data on water use – Water balance:

The water balance (Oke 1987): p = E + Δ r + Δ S sets precipitation (p), Evaporation (E), the net runoff (Δ r) and the net change in soil water storage Δ S in relation. Δ r = inflow – outflow. For Imp_DroP a mean daily summer water balance during a dry summer (JJA2022) (Fig. 1) for the area within the administrative border of Vienna (414.78 km^2) and its 1.897 Mio inhabitants were made. For comparison the available data was analyzed also for a "wet" (09.06.-20.06.2021) and an extreme dry episode (10.08.-20.08. 2022) (Fig. 2).

Relevant data to estimate the water balance within Vienna were retrieved (Annex A1). Unfortunately, no direct data on water consumption could be obtained. The city gardens (MA42) were only able to deliver 3 - annual data points of total water consumption, which includes use in sanitary rooms in administrative buildings of the MA42. On the other hand, from MA31 daily data for full years (Annex A2) and from EBS even hourly data (Annex A3) for the selected episodes could be obtained.

Figure 1. Average daily water balance for the area of Vienna - for a dry summer



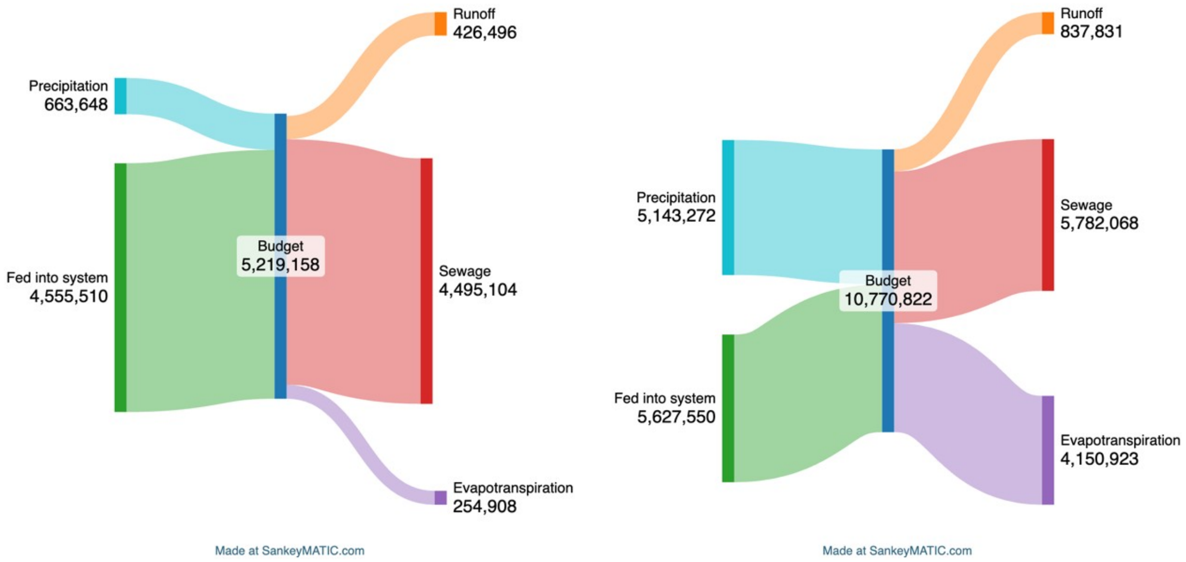


Figure 2. accumulated water balance for the area of Vienna - left: extreme dry episode, right: wet episode), Precipitation: Geosphere, HQ1-3: MA31, Sewage: EBS, Wien und Liesing: MA45

Precipitation: The mean daily precipitation for JJA2022 on this area was **680 000 m³**. This means 31 800 m³ on the water area (19.39 km^2), 431 730 m^3 on unsealed land (263.25 km^2) and 216 480 m^3 on sealed land (132 km2) (Stadt Wien 2025a).

Drinking water supply: There are three major supplies for drinking water in Vienna. The first one originating from the mountain regions of Schneeberg, Rax and Schneealpe can bring 220 000 m³ (Stadt

Wien 2025b). The second pipe originating from the mountain region of Hochschwab transfers up to 217 000 m³ water. The third Viennese water pipe (Wasserwerk Moosbrunn/Mitterndorfer Senke) can help to ensure water supply during high water demand periods or maintenance of the other pipes with a maximum water supply of 62 000 m^3 (Stadt Wien 2025c). Additionally, the groundwater plant Lobau can supply 80 000 additional m^3 of drinking water. There are smaller water suppliers which can give 10 000 m^3. In total this amounts to 589 000 m^3. The actual supply of high spring water pipes is controlled according to consumption. Most of the time there is more supply than demand. Only at times in summer can a slight decline be noticed (personal communication MA31).
The average daily water demand of **375 000 m³** can be met by the two high spring water pipes (I: 173 000 m^3, II: 202 000 m^3). During summer despite irrigation needs, the water demand generally is lower than in the rest of the year, because many Viennese inhabitants leave the city. The average daily water consumption of a person (without industrial use) is 130 l/Person -> 0.13m³ * 1.897mio = 246 610m³/t (Stadt Wien 2025d). The annual fluctuations in water supply are summarized in Stadt Wien (2025e).

Runoff Δ r - outflow: surface: The total Danube discharge is around 120 960 000 m^3 daily. The main changes in the Danube discharge volume close to Vienna are the outflow Marchfeld channel and the inflow of Wien and Liesing. For the Marchfeldkanal, which serves to stabilize groundwater levels and serve as irrigation supply in the important agricultural and especially vegetable region Marchfeld east of Vienna, 6000l/s are taken from the river Danube (https://marchfeldkanal.at). This amounts to 518 400 m³/day.
For the rivers Wien and Liesing (Oberlaa) discharge data are available via eHYD only until 2020, therefore data of the dry summer JJA2019 was used, which has a very similar discharge regime. The mean discharge for river Wien at the gauge Kennedybrücke amounted to 14 668 m^3. For the river Liesing at the Oberlaa gauge was 34 134 m^3, which amounts to a total of around **48 802** m^3 surface runoff from Wienerwald on average. Other potential runoffs of smaller creeks such as Erbenbach, Reisenbach or Schreiberbach were not considered, as their discharge was not available for the reference periods and likely to be clearly below 24m³ daily.

Runoff Δ r - outflow: groundwater: Further runoff of sealed and unsealed surfaces was considered. We assume that of the precipitation received by the 263.25 km² unsealed surfaces in Vienna, which are mainly forests, around 30% are not evaporated, but run off via surface or groundwater (Markart et al. 2009). Thus, the surface runoff not received by the sewage minus the discharge of Wien and Liesing results in the groundwater flow, which amounts to **80 717** m^3. This volume is finally destined to enter the river Danube and the black sea.

Runoff Δ r - outflow: sewage: 132 km^2 of Vienna is sealed. We assume that 95% of the precipitation that is received on sealed land is drained via the sewage system (drainage coefficient=0.95) and 5% (1.7 km²) of the Viennese roof areas are green roofs with a discharge coefficient of 0.5. This amounts to 20 462 m^3 of precipitation going to the sewage system where it mixes with greywater from the households, service and industry sector. Finally, through the main sewage treatment plant in Vienna (Ebswien 2025) exits the total amount of water drained by the Viennese sewage system, which amounts for roughly 500 000 m^3/day of purified water (Stadt Wien 2025f) entering the river Danube. This flow balances approximately the removal of Danube water by the Marchfeld channel. Minor amounts of water are used by MA48 to clean the roadway. These volumes mainly enter the sewage but are neglected in the water balance.

Change in ground water storage Δ S: For this special case the term Δ S is neglected as we assume that for three summer months water storage is depleted and filled to the same extent.

Evaporation: We assume that 100% of the water surfaces, 70% of unsealed surfaces, 5% of the sealed surfaces, 50% of the green roof area as well as all the water used for irrigation evaporate. The evaporation from water surfaces as the Danube is neglected.

Irrigation: Irrigation within Vienna is done mainly using drinking water – taking the high spring water pipes (HQs) as input but allowing the water to evaporate within Vienna instead of discharging to the sewage.
Regarding the irrigation volumes we have the following information: 300 000 m^3 are used annually in irrigation vans. If we divide this value by 120 days (4 months of irrigation) we obtain 2500 m^3/irrigation day (personal communication Gruber/MA31). One tank can hold 750l (Fig. 3) and in the 18^{th} and 19^{th} district one tank is emptied 3-4 times per day (2 625 l/ 2.625 m^3) (personal communication with a gardener). This indicates around 900 - 1000 tanks are operating in Vienna.
We did not receive any specific information about irrigation volumes used by MA42 or billed by MA31. Nonetheless from the data showing the amount of drinking water fed into the system an increased water demand is visible during dry and hot summer 2021 (Annex A2). This could be accounted for irrigation of green areas (and/or increased frequency of showers). As the sewage levels don't increase (Annex A4) – it is likely that the water is lost via evapotranspiration.
Some water is strayed in highly frequent areas to increase thermal comfort (Stadt Wien 2025g). These "mist showers", which start operating at a daily maximum temperature of 30 °C use only a negligible amount of drinking water (Mitterhauser 2022).

Figure 3. Irrigation tanks in Vienna 18th district holding 750l (left) and Laxenburg (right)

Annex A2 shows an increase in water fed into the system, which is directly related to water consumption in Vienna, during the dry first half of the summer 2021 which is very likely to be caused by the precipitation deficit during this period (Annex A4). This possibility was confirmed by MA31. The average spring precipitation sums at Wien Hohe Warte for 1961-1990 are 155 mm and 196 mm. In 2020, 2021 and 2022 the spring sums were 114, 125 and 103 mm. The summer precipitations sums were 271, 255 and 151, making 2022 an extremely dry summer combined with an extremely dry spring. In Annex A5, the dryer the summer the more negative the correlation between drinking water consumption and precipitation gets.

M3b.4 Quantification of irrigation needs (green roofs)

For the two measurement years June 2022 till December 2023 the calibrated FAO model shows good agreement at all measurement sites with slight overestimation at medium evaporation rates in the simulation (see as example, the AKH roof site Fig. 7; results of the other three green roof sites including a detailed explanation can be found in Annex A 12). The identified critical factor for calibration of the FAO model is the crop factor (Kc) due to its temporal variability at green roofs under rainfed conditions, which was fitted against the measured course of actual evapotranspiration. Using AKH site as a calibration site, the next step was the validation of the model at the other sites. Fig. 8 shows the course of the measurements and simulation of actual evapotranspiration in the second measurement year of 2023 (for all years and green roof sites see figures in the Annex A 13).
As can be seen several deviations in the daily time step occurred, although we already removed days with rain. These deviations are based on uncertainties, which are caused by measurement disturbances causing measurement gaps and the use of proxy data for precipitation and global radiation and partly wind from a representative Geosphere weather station (Hohe Warte) for the simulation. In Fig. 8 for AKH as well as in the results from the other three sites (Annex A 13) we can see the differences of measured evapotranspiration between the extensive and intensive lysimeter pot. It reveals that the thickness of the soil substrate layer is important for the duration of drought stress or vice versa total evapotranspiration through extended evaporation periods under starting drought but made not much difference for the maximum evapotranspiration rate between the two used vegetation types of the two pot types. These effects were quantified further using the calibrated simulation of all 4 sites (Annex A 14).

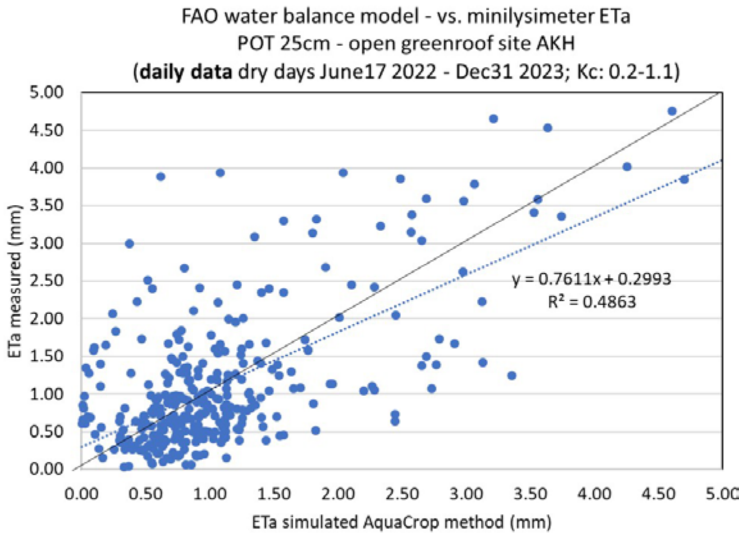


Figure 7. Comparison of daily actual evapotranspiration measured by mini lysimeter vs. simulated by the FAO method (calibrated for the two measurement years and fitted Kc factor for the intensive pot (25cm substrate depth); green roof site, AKH, Vienna

Based on the calibrated green roof water balance model (FAO-model) we calculated the soil water balance components for each green roof site experiment for selected past years (Annex A 14; Fig. 8a -AKH; Annex A 15) for the other three green roof sites. Compared to the rainfed conditions, the irrigated cases (see Fig. 8b left vs. Fig. 8c right for AKH site; Annex A 14, Annex A 16) show a 2-3-fold (400mm vs. >1200mm) increase in annual actual evapotranspiration (and related cooling potential), depending on the year and its specific weather pattern, respectively.

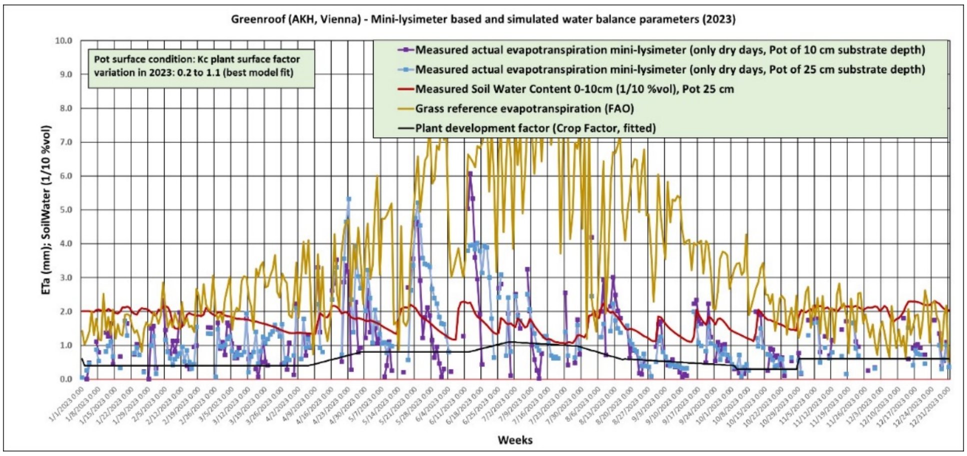
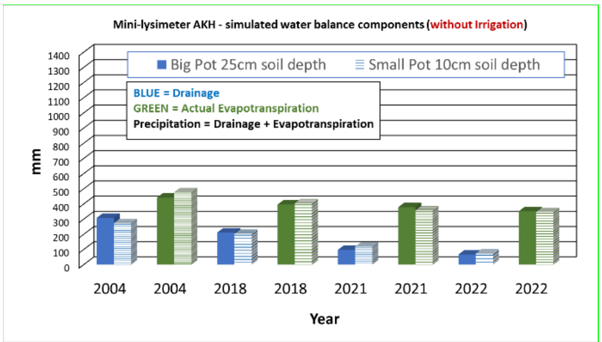


Fig. 8a. Grass reference evapotranspiration (FAO scheme simulated), daily measured actual evapotranspiration (for both extensive and intensive lysimeter pot), measured soil water content and fitted crop factor for Pot 25 cm (intensive); green roof site AKH, Wien



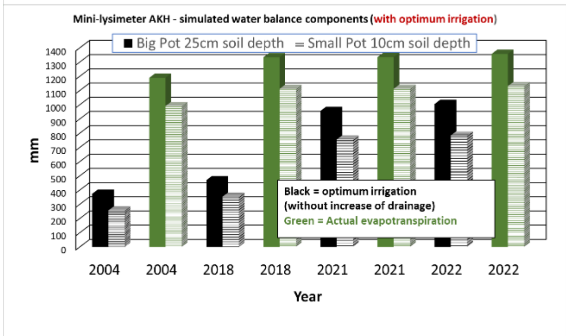


Fig. 8b (left) Simulated annual water balance components of wind-exposed AKH green roof site of different years for rainfed conditions (see also Tab. Annex A 14); 8c (right) Simulated annual water balance components of wind-exposed AKH green roof site of different years for optimum irrigation scenario (see also Tab. Annex A 14).

A further analysis over the four simulated years of significant different annual precipitation pattern (2004, 2018, 2021 and 2022) is respect to the drainage potential shows a high correlation between annual precipitation and drainage, considering all measurement sites and extensive and intensive green roof substrate (Fig. 9a-b). Small differences in drainage between 25cm and 10cm soil depth (pot based) are obvious. The slightly higher response at the intensive pots with 25cm soil depth was probably caused by the recorded decreased vegetation cover/activity under rainfed conditions due to summer drought stress (vegetation type was more sensitive to drought stress, decreasing actual evapotranspiration due to inactive vegetation). Therefore, in case of support irrigation to maintain the cover vegetation growth, a lower response and drainage rate in respect to precipitation can be expected.

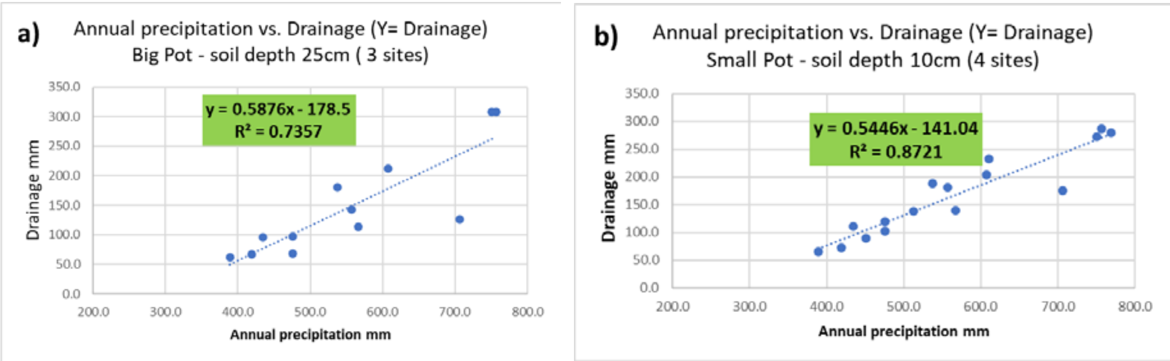


Figure 9a-b: Simulated relationship between annual precipitation and drainage from the two investigated green roof substrates a) intensive and b) extensive.

M3b.3 Provide soil water content data for agricultural areas

Using the GIS-based Agricultural Risk Information System (ARIS) (Eitzinger et al. 2024), which includes a crop-specific drought monitoring scheme, soil water content can be derived at the 1 km grid level using relative soil saturation (RSS) and field capacity. The RSS describes the plant-available soil water depletion over two soil layers (topsoil and subsoil) for the main crops (maize, spring barley, winter wheat) as well as grassland and considers the specific growing seasons for the different crops in the region around Vienna.

For this study, the daily RSS were calculated for four time periods: 15.07-26.07.2004, 06.08-17.08.2018, 09.06-20.06.2021 and 10.08-20.08.2022. For June, the RSS values of winter wheat were used (2021), for July and August the average RSS between the summer crop maize and winter wheat, which was simulated as fallow from mid-July (2004, 2018, 2022).

To obtain the actual evapotranspiration for the different crops as output, the ARIS model was reprogrammed to allow calculation for the selected periods. The actual evapotranspiration was then used for the evaluation of the regional climate model WRF (Annex A 17).

The in-situ measurement data on the various green roofs in Vienna was used as input for the FAO model scheme (Allen et al. 1998).