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Water recharge in the dune belts of Donana National Park estimated with a high-precision weighing lysimeter

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Summary

Although precise weighing lysimeters are mostly installed for agricultural purposes in crop-producing areas, these instruments are also useful in areas of ecological interest where soil and aquifer recharge-discharge processes need to be better understood. In September 2015 a high precision meteo lysimeter was installed in a coastal dune of the Doñana Natural Reserve to quantify the recharge in dune belts, and to estimate its dependence on regional climate trends. In addition to the lysimeter, also six soil moisture sensors and 2 meteorological stations were installed. The first results show recharge rates ranging from 19 to 97%, depending on the meteorological conditions and the initial soil moisture. The lysimeter-measured rainfall exceeded the measurements of the tipping bucket by 1 to 19 mm. Also the contribution of the dew was detected by the lysimeter. A soil water model is currently being set up to simulate recharge, soil water movement, evaporation and percolation, as well as to quantify uncertainty and noise effects.

Introduction

Dune belts are fundamental for groundwater recharge in coastal aquifers and constitute therefore a key location for the quantitative and qualitative monitoring of water resources in ecological habitats. Beyond the large number of methods for recharge estimations, at the moment weighing lysimeters yield the most precise and realistic measures for evapotranspiration and precipitation (Peters et al. 2014). In the same way, it is a direct tool to measure water recharge because of its technology in weight measurement of drained water, representing groundwater. Nonetheless, precise weighing lysimeters have been mostly installed for agricultural purpose in crop areas and therefore only limited knowledge exists about recharge dynamics and its dependence on meteorological parameters in dune belts.

The Geological and Mining Institute of Spain (IGME), in collaboration with the Biological Station of Doñana (EBD-CSIC), started recently a research project to monitor the natural recharge in the dune belts of the Doñana Natural Reserve. A high precision weighing meteo-lysimeter with lower boundary control was installed in September 2015 for continuous monitoring of recharge and other soil and meteorological parameters.

Recharge in the dune belt is essential for the conservation of the groundwater dependent wetlands of the Doñana National Park, which is threatened by intensive agricultural irrigation and water supply for tourism. The main objective of this study is to quantify the recharge in dunes belts within semiarid climate, and its dependence on regional climate trends predicted by climate models.

Material and Methods

The site is equipped with a UMS (UMS AG, Munich, Germany) weighing lysimeter (1.65 m diameter, 1.50 m height and a weighing resolution of 10 g), six CS650 soil moisture sensors (Campbell Scientific, Logan, UT) installed at 0.30, 0.60, 1.20, 1.60, 2.20, and 3 m depth, and 2 automatic meteorological stations (Vantage PRO2 Davis, California, USA; UMS AG, Munich, Germany). The lower boundary condition at the bottom of the lysimeter is controlled using a tensiometer. A peristaltic pump maintains the bottom of the lysimeter at the same potential as measured by the field tensiometer installed outside the lysimeter. Rainwater and water drained from the lysimeter is collected and sampled for analysis of hydrochemistry and stable isotopes. *Table 1* shows the measurements that are continuously performed. Physico-chemical soil properties such as density, grain size, mineralogy and metals were also analysed at different depths.

To eliminate measurement noise the raw data are corrected to accurately calculate precipitation (P), evapotranspiration (ET), as well as recharge (R) from lysimeter data. The time-series of lysimeter weight and drainage water quantity can be affected by a wide variety of singular disturbances, which add to the measurement noise. Examples are the withdrawal of water from the drainage sampling vessel, sudden changes in weight when vegetation is removed, maintenance work, operators stepping on the lysimeter surface, and so on. Detection and correction of such singular events was performed by suitable filters and manually in some cases (Schrader et al. 2013).

For the calculation of cumulative ET and P we applied the AWAT filter (Peters et al. 2014) in order to reduce intrinsic

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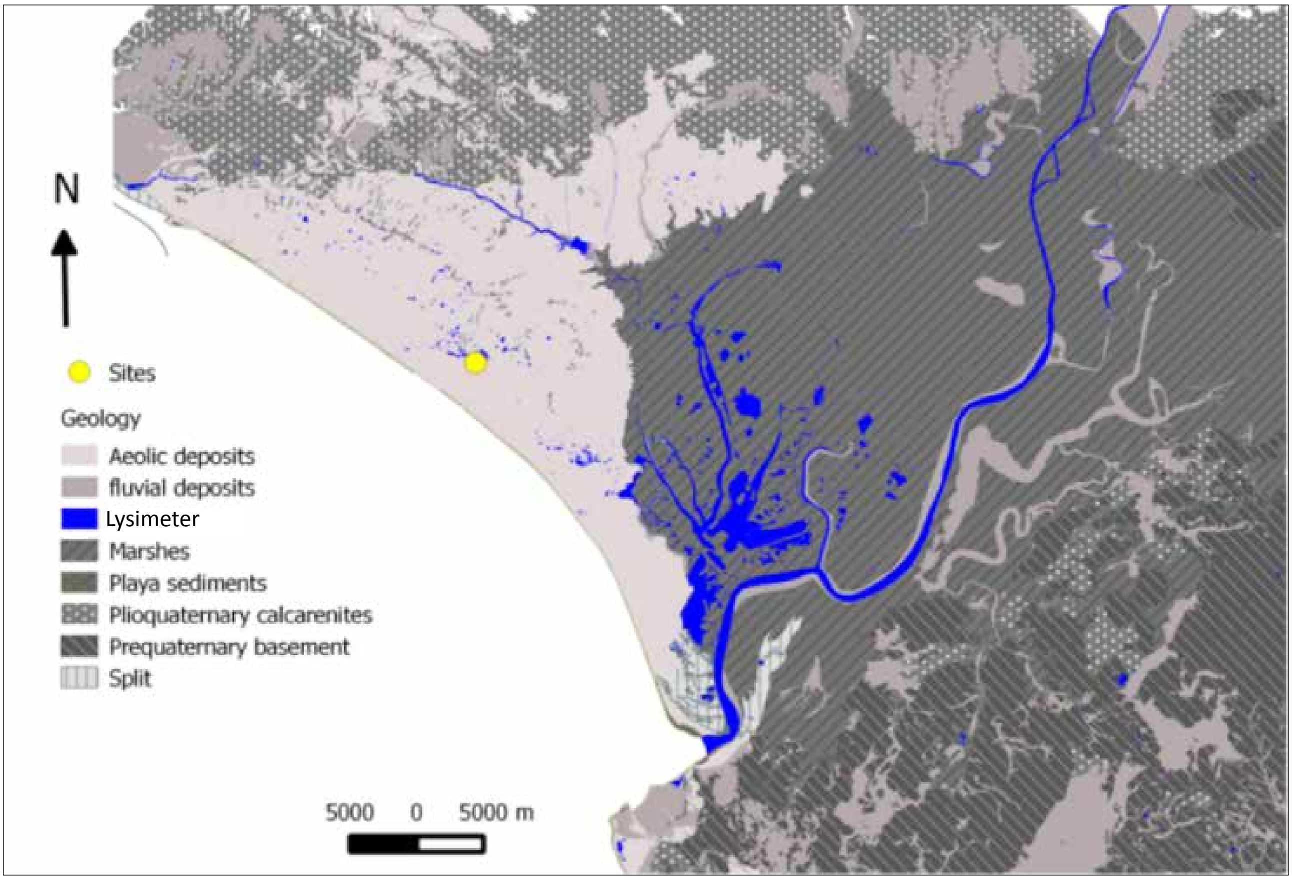

Figure 1: **Meteo-Lysimeter placement, located in Doñana National Park, province of Huelva, Southwest of Spain (source: Kohfahl et al. 2011 and wikipedia.com).**

Table 1: **Measured parameters and intervals.**

Measured parameter	Time interval
Soil mass lysimeter	1 minute
Water mass drained from lysimeter	1 minute
Soil water tension	10 minutes
Soil moisture	10 minutes
Wind direction	10 minutes
Wind velocity	10 minutes
Net radiation	10 minutes
Precipitation	10 minutes
Air humidity	10 minutes
Air and soil thermal profile	10 minutes
Soil bulk density	Once
Grain size distribution	Once
Mineralogy	Once
Metals content	Once

noise in lysimeter data by smoothing. This method has been recently applied in other studies (Hoffmann et al. 2016). For the application of the AWAT algorithm, the parameters maximum window width and maximum threshold were set to 31 min and 0.24 mm, respectively. Due to power failures, there are several gaps along the time series which were cut from lysimeter data but not from the rest of instruments, for instance the tipping bucket rain gauge.

According to the soil water balance the infiltrating rain water increases soil moisture and groundwater R, assuming that the surface flux is zero.

Precipitation = Recharge + Evapotranspiration + Soilwater storage (1)

Within the rain periods air saturation is 100% and no ET is assumed to occur. Therefore P and ET have been calculated as follows (Schrader et al. 2013):

$$\Delta W = \Delta w_{lys} + \Delta w_{drain}$$

$$\Delta P = \begin{cases} \Delta W, & \Delta W > 0 \\ 0, & \Delta W \leq 0 \end{cases}$$

$$\Delta ET = \begin{cases} \Delta W, & \Delta W < 0 \\ 0, & \Delta W \geq 0 \end{cases}$$

where Δw_{lys} [kg] is the mass change of the lysimeter between two time steps, Δw_{drain} [kg] is the mass change in the drainage sampling vessel, ΔP [kg] is the sum of precipitation recorded by the lysimeter, ΔET [kg] is the corresponding evapotranspiration, and ΔW [kg] is the change in cumulative upper boundary flux in the corresponding time interval. Note that due to the 1 m² surface of the lysimeter weight in kilograms is equal to a change in millimetres or L per m². R was measured directly by drainage weight.

First Results and Discussion

Data from cumulative Δw_{drain} and cumulative Δw_{lys} are represented in *Figure 1a* without previous treatment. In the graph it is easily recognise the moments where withdrawal of water from the drainage sampling vessel take place because of the characteristic straight fall in the curve. This kind of errors are automatically, or sometimes manually, corrected.

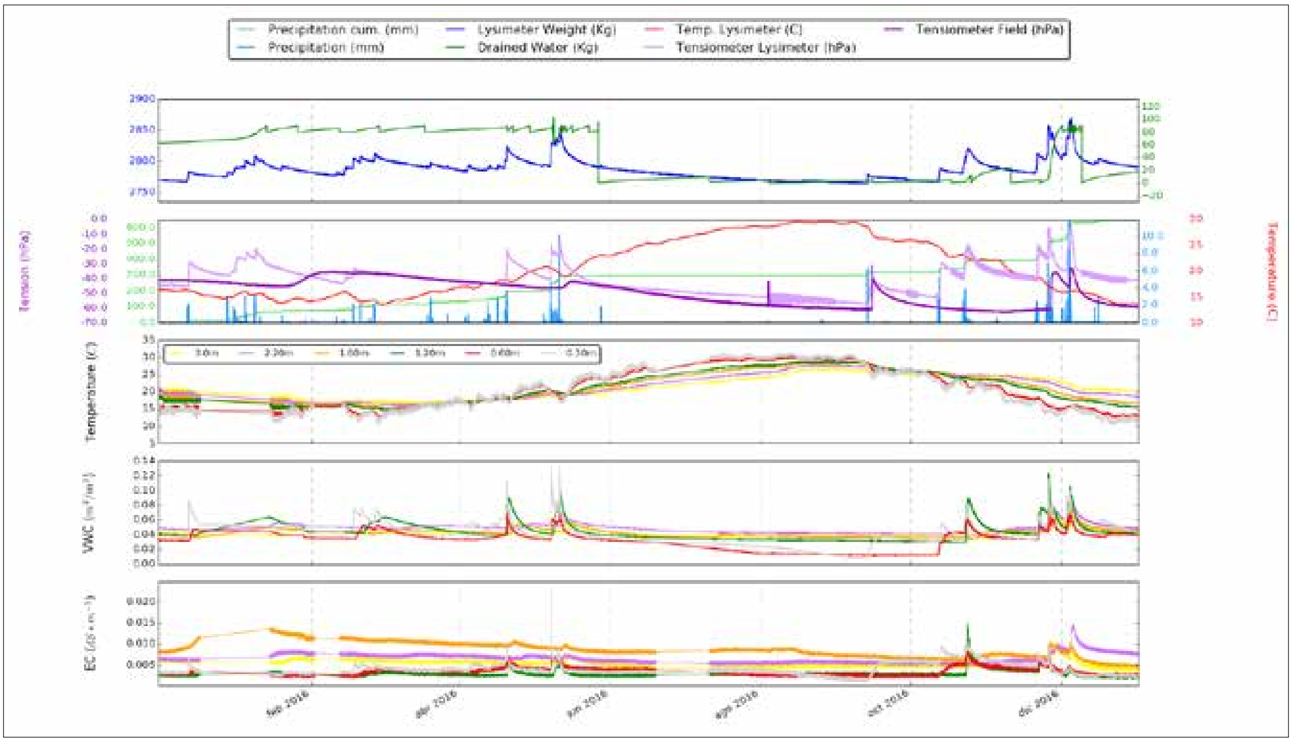

Figure 2: **a) Cumulative mass change of lysimeter (kg) and cumulative mass change of drainage vessel (kg); b) P measured by tipping bucket rain gauge (mm) and its cumulative P (mm), results from tensiometer in field and in lysimeter (hPa), temperature from lysimeter at 1.40 m depth (°C); c) Temperature profile in field measured by CS650 soil moisture sensors (°C); d) Volume Water Content (VWC) measured by CS650 soil moisture sensors (m³/m³); e)Electroconductivity (EC) measured by CS650 soil moisture sensors (dS/m).**

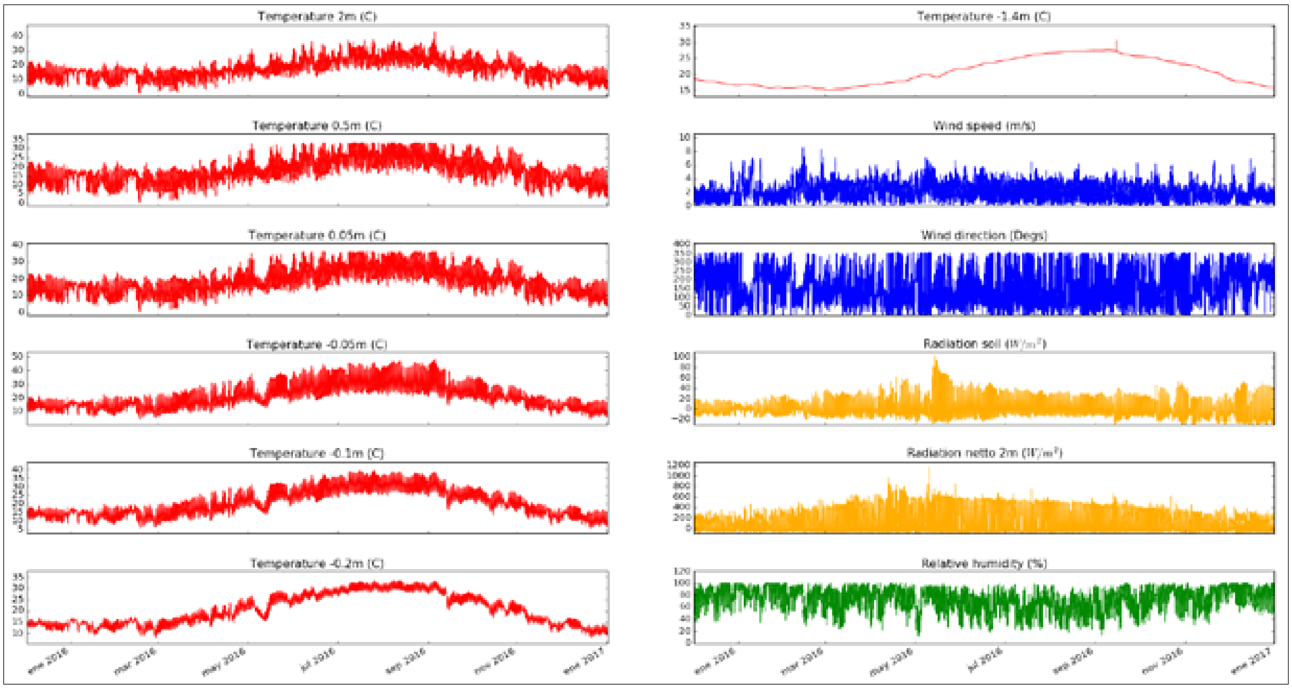

Figure 3: **Meteorological parameters measured every 10 minutes. Values given in m refer to distance from soil surface.**

Results show differences between tensiometer in field and tensiometer in lysimeter (*Figure 1b*). In September 2016 the tensiometer located in field was replaced. Recently the differences of around 30 hPa between both curves have significantly reduced, presumably due to the new tensiometer installation. In the graphs 1c, d and e are represented temperature, soil misture, and salinity measured from the six CS650 soil moisture sensors at different depths. These data will be used for recharge estimation with Hydrus 1D benefitting from the possibility to compare it with direct measurements. Data from more climatic parameters measured within 10 min intervals are represented in *Figure 2*: temperature pro-

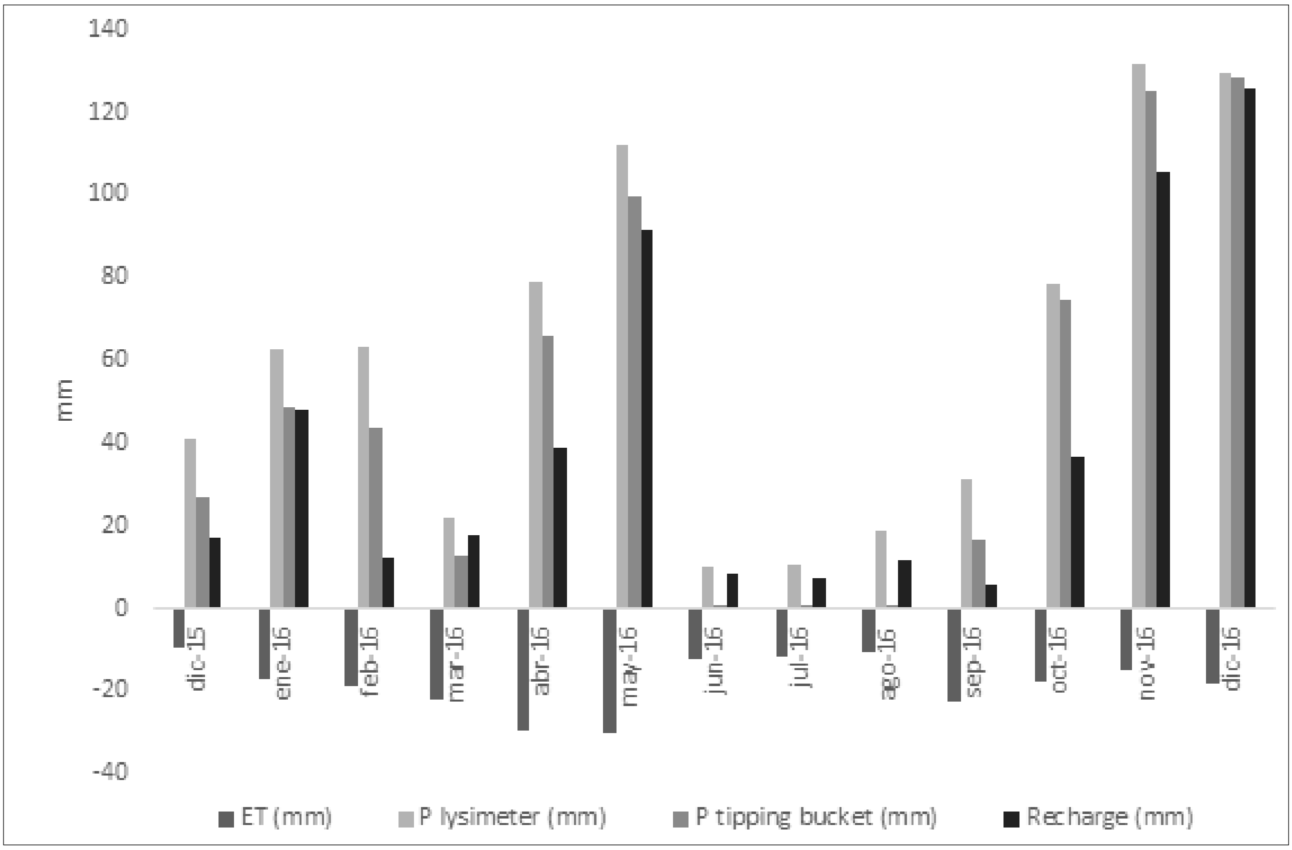

Figure 4: **Monthly evapotranspiration (ET) and rainfall (P_l), both calculated using lysimeter data, rainfall measured with the tipping bucket rain gage (P_g), and recharge (R), measured as weight increase due to drained water of the lysimeter into the sample vessel, from December 2015 to December 2016.**

file, wind speed, wind direction, net radiation, and relative humidity. All these data are used as input parameters to set up a model with HYDRUS1D for calculating recharge.

Results show higher P measured by lysimeter and drainage weight compared to the tipping bucket rain gauge data. The largest differences are observed between December 2015 and May 2016 whereas from October to December 2016 the differences are below 5%. Small differences may be related to dew effects registered only by the lysimeter but larger differences between December 2015 and May 2016 are attributed to technical problems during the first part of the measurement period which have not been clarified so far.

Within the summer months although no rainfall was detected by the rain gauges some weight increase of 10-18 mm/month was measured by the lysimeter (*Figure 2*) which is attributed to dewfall, reported to be very intense in the area by other studies (REFERENCE). The dew contribution is usually not recorded by the tipping bucket rain gauges due to its limited resolution.

The amount of monthly R ranges between 19 and 97% of the P calculated by the lysimeter (see *Figure 2*). Possible reasons are still under investigation and may be due to initial water saturation of the sediment, meteorological conditions, but also to technical problems related with the field tensiometer which was replaced in September 2016.

To better understand the uncertainty of measurements a soil water model is currently being set up and calibrated by lysimeter and soil moisture sensor-acquired data to better quantify (i) the effect of meteorological parameters on R rates, (ii) to simulate the effect of uncertainty in precipitation measurements on simulated R, (iii) to verify the dew effect and (iv) to quantify the effect of the lower boundary condition on measured hydrological components by the lysimeter.

Conclusions

The collected data in the first hydrological year have shown the satisfactory performance of the equipment. There are differences in P measurements between the tipping bucket rain gauge and the lysimeter, and a characteristic effect it is observed during summer where no P is measured by pluviometer but a positive increase in ΔW is detected attributed to dew. Also differences in monthly R are measured. A model, HYDRUS1D, is currently set up to evaluate all these processes. With the ongoing studies we will try to answer the questions that have been exposed in this research.

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