Response to Interactive comment Anonymous Referee #2 2017-10-05

Regional soil moisture monitoring network in the Raam catchment in the Netherlands.

General comments:

(1) Comment: *The study describes the implementation of a new in situ soil moisture monitoring network in the Raam catchment in the Netherlands. It is definitely relevant to the HESS journal. I think the paper is well written and well presented. I think the methodology is thorough and well explained, with a concise description of the calibration techniques employed. I have only minor comments regarding the validation. In particular, the data series analysis could be improved by demonstrating the influence of soil type and vegetation on the soil moisture measurements over the validation year.*

Reply: We thank the reviewer for the assessment. We appreciate the valuable suggestions provided to improve the manuscript. Below are our responses to the comments and points raised.

Regarding the comment on the data series analysis we refer to our response to comment 3.

Specific comments:

(2) Comment: *Section 3.1: The stations are densely situated with stations located 15km apart on average and some stations just 2.5 km apart (e.g. 1 and 4). So you would presumably need a very high resolution land surface model or hydrological model to resolve such small scale variability. Please give some examples, perhaps referencing studies for similar size networks.*

Reply: We refer to Sect. 3.1, where six networks, which are comparable in density, are listed. A soil moisture network of such density is advantageous for various reasons:

- The measurements can be used for validation of coarse-scale soil moisture products such as SMOS and SMAP. Soil moisture can exhibit a large spatial variability; the sub-footprint spatial standard deviation of point-scale soil moisture measurements often exceeds the E_{RMS} accuracy goal for SMOS and SMAP (E_{RMS} = 0.04 m^3 m^{-3}) (Crow et al., 2012; Famiglietti et al., 2008). Multiple soil moisture measurements within the footprint of a coarse-scale soil moisture product reduces the measurement uncertainty of a footprint-scale soil moisture reference. We explain this in Sect. 3.1 of the manuscript (also see the proposed change at comment 9 of Reviewer #1).
- In hydrological research there is a trend towards hyperresolution land surface modelling (Beven et al., 2015; Wood et al., 2011). Wood et al. (2011) propose to have land surface models at continental scales that have a grid resolution of 100 m by 100 m. Another example is the Netherlands Hydrological Model (NHI) that is currently operating at a spatial resolution of 250 m by 250 m (De Lange et al., 2014).
- Stations 1 to 5 are located in the sub-catchment Hoge Raam ('High Raam') of the Raam catchment, which is relevant for hydrological catchment studies. We refer to comment 7 of Reviewer #1 for a more in-depth explanation.

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(3) Comment: *Section 4.3.2: Information is missing regarding the influence of soil type and vegetation on the soil moisture measurements over the validation year. For example, for sandy soils you would expect to find a smaller dynamic range than clay soils. Was this evidenced in your results? It would be useful to see soil moisture time series plots for stations with different soil/vegetation types.*

Reply: We agree with this comment. We have plotted soil moisture measurements averaged for different soil types, groundwater depths and vegetation characteristics. We propose to add the following text and figure to the manuscript:

In Sect. 4.3.2 (page 10 line 23):

"We explored the influence of various factors on soil moisture dynamics. Figure X shows the average of soil moisture measurements at 20 cm at stations with a specific characteristic. Fig. Xa shows the average soil moisture content for stations in sandy soils and for stations in loamy/clayey soils. We expect sandy soils to have lower and more dynamic soil moisture contents than loamy/clayey soils, which Fig. Xa confirms. Fig. Xb shows that locations with deep groundwater levels (> 1 m) generally are drier than locations with shallow groundwater levels (< 1 m). The situation of shallow groundwater levels applies to the stations 1, 6, 8, 11, 12, 13 and 15, based on groundwater level measurements by the regional water authority Aa en Maas. Fig. Xc shows the variation in soil moisture content due to different vegetation types. In general, the soil moisture content is larger in corn fields in comparison with the other vegetation types. Also, grasslands tend to be wetter than fields with sugar beets and onions in the winter period of 2016/2017.

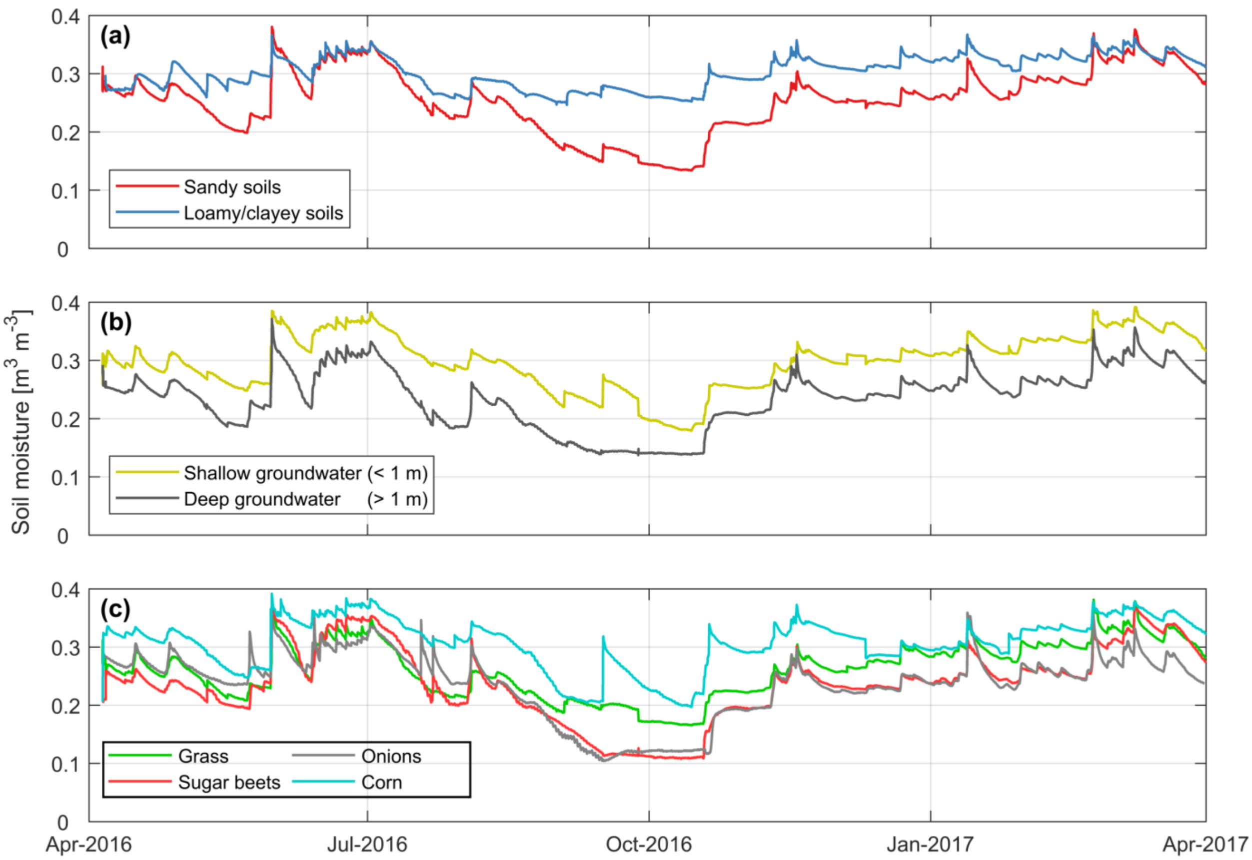

Figure X: Influence of (a) soil type (Table 2), (b) groundwater depth (based on groundwater level measurements by the regional water authority Aa en Maas) and, (c) vegetation type (Table 3) on soil moisture dynamics at 20 cm depth."

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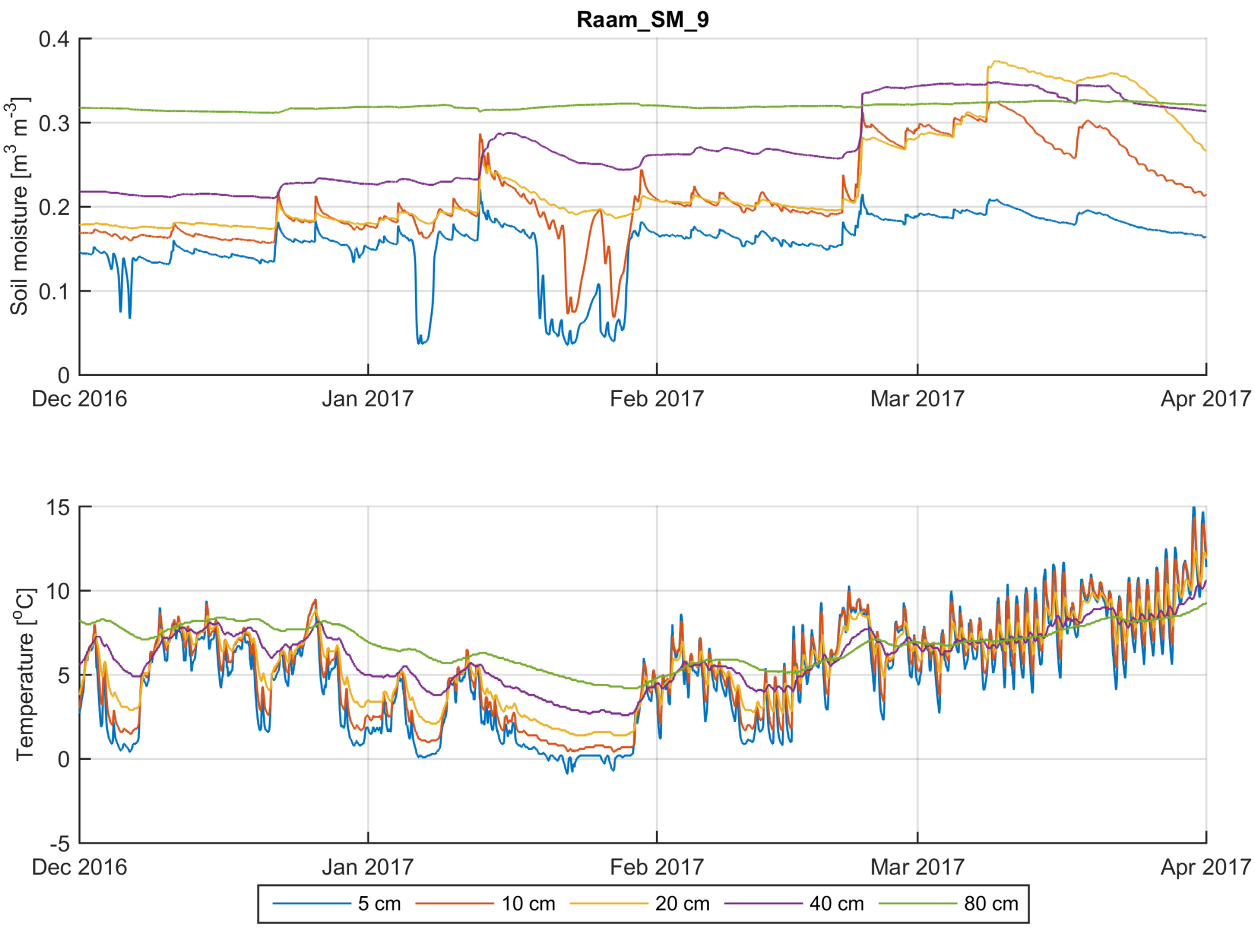
(4) Comment: *Section 4.3.3: Most soil moisture measuring devices malfunction when soils are frozen. This can lead to spurious low values (e.g. Hallikainen et al 1985). Did this affect any of the stations during the validation period and could this potentially be an issue? If so, would it be possible to plot the soil moisture for a station during frozen conditions?*

Reply: It is correct that the soil moisture sensors do not record reliable soil moisture values when soils are frozen. However, we would like to note that the sensors do not really malfunction. When soils are (partly) frozen, the free water content decreases and this affects the bulk dielectric permittivity (which is what soil moisture sensors actually measure). The figure below shows an example of this phenomenon. During periods when the temperature, which is measured by the same device, is close to 0 °C, the soil moisture content as measured by the sensor decreases sharply. The exact temperature below which soil moisture measurements are affected depends on the soil moisture, soil texture, and the temperature profile (Watanabe and Flury, 2008). Therefore, it is tricky to give a threshold temperature below which the soil moisture measurements are affected.



Soil moisture content and temperature recorded at station 9 during the winter period

The difference in dielectric permittivity between unfrozen and frozen conditions could be of use for other studies, because it gives information about the free and frozen water contents. Therefore, we do not remove these data from the measurements series on beforehand.

We propose to add the following to Sect. 4.3.3 (page 11 line 9).

"When soils are frozen, the free water content decreases and this affects the bulk dielectric permittivity. Users of the soil moisture data are recommended to remove the affected soil moisture measurements from the measurement series. The measurements do give information about the free and frozen water contents. Together with the simultaneous soil temperature measurements this could support research to the process of the freezing of soils."

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(5) Comment: *Section 5: I also found the website a bit unintuitive. Please make it easier to find the data.*

Reply: We agree with the comment. We will provide a direct link to the dataset: https://doi.org/10.4121/uuid:dc364e97-d44a-403f-82a7-121902deeb56 instead of https://doi.org/10.4121/uuid:2411bbb8-2161-4f31-985f-7b65b8448bc9. The first link leads to the dataset concerning the period 2016-04-05 to 2017-04-04. The second link leads to the so-called data collection. The dataset is part of this data collection. New data (e.g. the period 2017-04-05 to 2018-04-04) will be added to the data collection in due time. We propose the following changes to the manuscript.

In the abstract (page 1 line 25-26):

"The data ~~is~~ are available at https://doi.org/10.4121/uuid:dc364e97-d44a-403f-82a7-121902deeb56~~http://dx.doi.org/10.4121/uuid:2411bbb8-2161-4f31-985f-7b65b8448bc9~~."

In Sect. 5 Data availability (page 11 line 11-13):

"The soil moisture and temperature data are available at the 4TU.ResearchData data centre at https://doi.org/10.4121/uuid:dc364e97-d44a-403f-82a7-121902deeb56~~http://dx.doi.org/10.4121/uuid:2411bbb8-2161-4f31-985f-7b65b8448bc9~~. The data are found under the 'DATA' header. The data set currently covers the period between 5 April 2016 and 4 April 2017. New data will be added to the data collection at https://doi.org/10.4121/uuid:2411bbb8-2161-4f31-985f-7b65b8448bc9."

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(6) Comment: *Section 6: In the conclusions section it might be good to add some information on future work that is expected to result from this study. What particular models/data assimilation systems might people be interested in using?*

Reply: We agree to add suggestions for applications of the soil moisture measurement series, although we hesitate to mention particular models or applications because the measurement series can be used for a wide range of applications.

We propose to add the following to the conclusion (page 11 line 30, also see comment 7 of Reviewer #1):

"The soil moisture measurement series of the Raam monitoring network provide a valuable data set for researching water management applications of soil moisture information, for validation of earth observation retrievals at coarse-scale and field scale, for studying processes in the unsaturated zone, and for validation of land process models. Stations 1 to 8, 10 and 12 to 15 can be used for modelling the catchment behaviour of the Raam Catchment."

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(7) Comment: *Figure 3: Perhaps use a different colour scale to show better the GHG variability*

Reply: We agree with the comment and propose the following change:

Old figure:

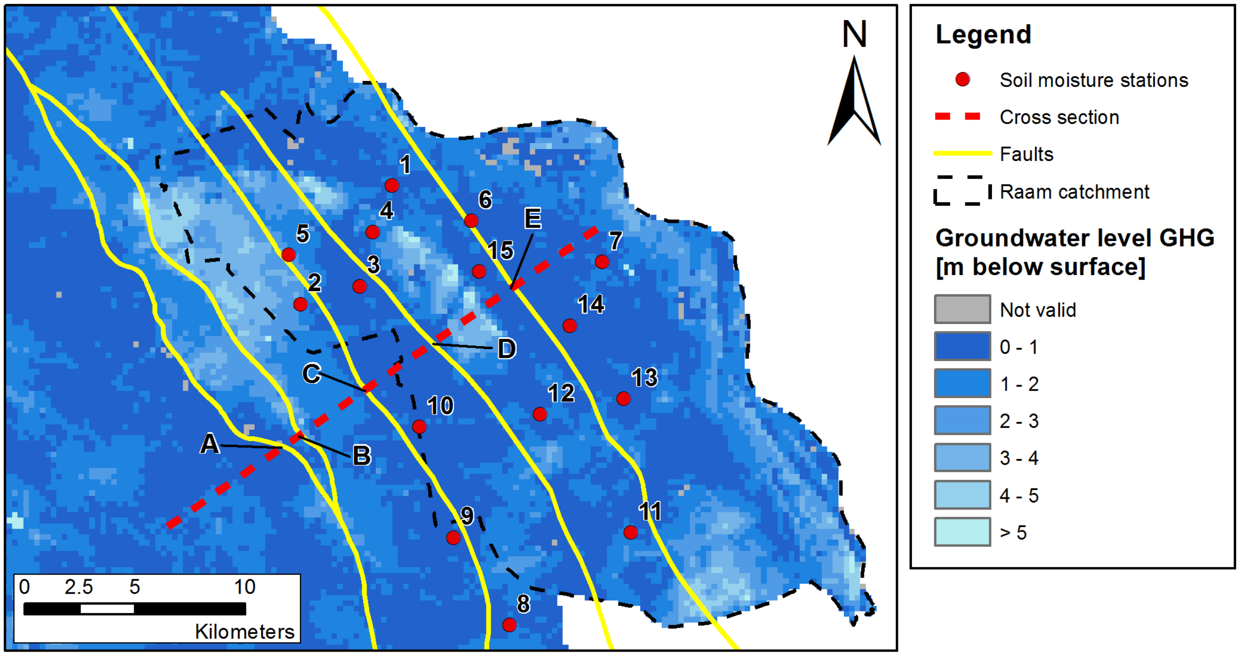
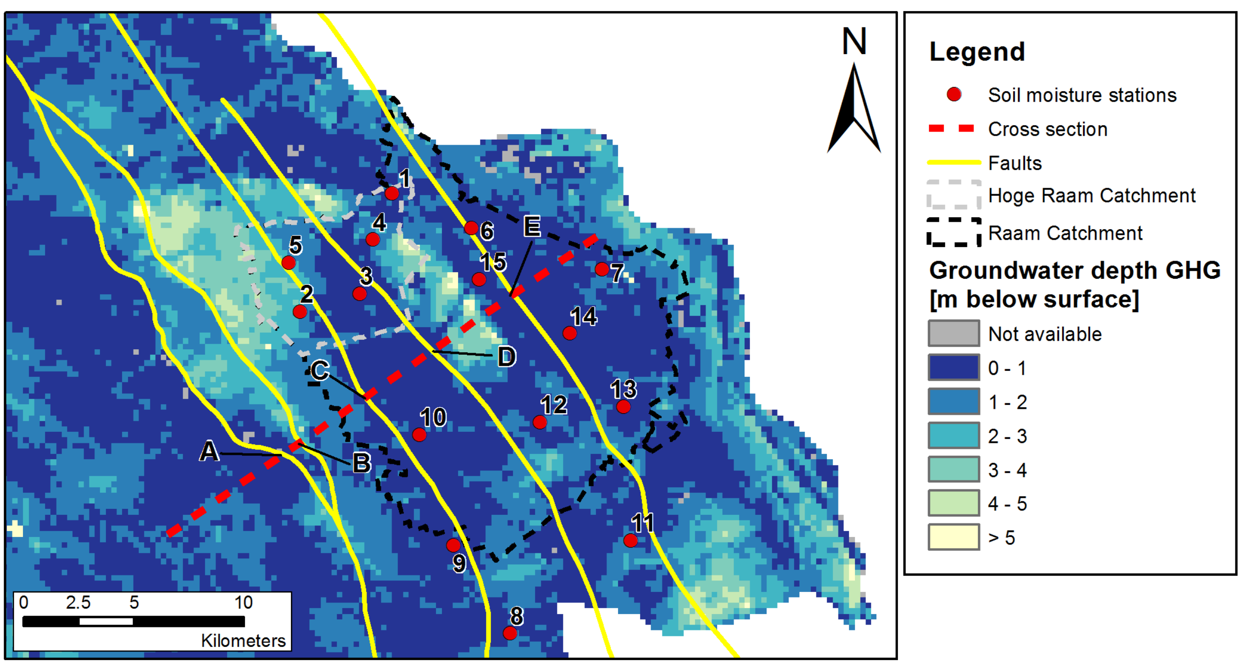


Figure 3: Mean highest groundwater depth ('gemiddeld hoogste grondwaterstand', GHG) in the Raam Catchment. The GHG is a long-term average of highest groundwater depths, defined as the average of the three highest groundwater depths per year over a period of 8 years. The groundwater data originates from the national implementation (NHI LHM) of the Netherlands Hydrological Instrument (De Lange et al., 2014). The map also shows the location of faults in the area. The dashed red line represents the cross section that is shown in Fig. 4.

New figure:



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(8) Comment: *Table 2: Could be refined a bit. References could be removed from the column headings and put in the caption instead.*

Reply: We agree that the table must be refined to improve readability. Because the table becomes too wide, we propose to split the table in two tables: one for soil type (new Table 2) and one for land cover (new Table 3). We simplified the column headings of the new Table 2. For more information on Table 3, we refer to our response to comment 10 of Reviewer #1. We propose to following changes in the manuscript:

In Sect. 3.1.2 (page 6 line 2):

"The soil moisture stations were installed at the border of fields for practical reasons. Table ~~2~~ 3 lists the land cover~~s~~ of the adjacent fields in 2016 as well as the land cover at the exact location of the soil moisture stations in 2016~~of the fields adjacent to the soil moisture stations~~."

New Table 2:

Table 2: Characteristics of the soil moisture monitoring stations

Station	Soil description[1] ~~Soil description and classification code from BOFEK2012~~	Soil order[2] ~~Approximate Soil Order Equivalent in the~~	% Sand (>50 µm)	% Silt (50-2 µm)	% Clay (<2 µm)	% Organic matter
1	Weakly loamy sandy soil on sub-soil of coarse sand (305)	Podzols	91.3	1.9	3.5	3.3
2	Weakly loamy sandy soil on sub-soil of coarse sand (305)	Podzols	90.4	3.7	2.1	3.8
3	Weakly loamy podzol soil (304)	Podzols	93.3	2.4	1.9	2.4
4	Weakly loamy sandy soil on sub-soil of coarse sand (305)	Podzols	90.0	2.0	2.9	5.2
5	Weakly loamy sandy soil with thick man-made earth soil (311)	Anthrosols	93.1	2.3	1.1	3.5
6	Clayey sand on sand (fluvial) (409)	Anthrosols/ Vague soils	83.7	4.8	9.9	1.6
7	Loamy sandy soil with thick man-made earth soil (317)	Anthrosols	82.1	10.5	5.2	2.2
8	Weakly loamy podzol soil (304)	Podzols	92.8	1.6	1.4	4.1
9	Weakly loamy podzol soil (304)	Podzols	95.4	1.1	0.8	2.6
10	Weakly loamy podzol soil (304)	Podzols	96.3	0.8	0.7	2.2
11	Weakly loamy podzol soil (304)	Podzols	94.8	1.7	1.6	1.9
12	Weakly loamy podzol soil (304)	Podzols	92.0	2.5	1.7	3.9
13	Weakly loamy soil partly on sub-soil of coarse sand (309)	Podzols	96.7	1.1	0.8	1.4
14	Loamy podzol soil (312)	Podzols	90.0	4.7	2.3	3.0
15	Weakly loamy sandy soil with thick man-made earth soil (311)	Anthrosols	88.6	5.5	2.8	3.1

[1] Soil description and classification code from BOFEK2012 (Wösten et al., 2013)
[2] Approximate Soil Order Equivalent in the World Reference base (Hartemink and De Bakker, 2006)

New Table 3:

Table 3: Land cover near the soil moisture monitoring stations

Station	Land cover of adjacent field in 2016	Land cover at location of station in 2016
1	Grass	Grass
2	Sugar beets	Grass
3	Grass	Grass
4	Grass	Grass
5	Onions	Grass fallow
6	Natural grass	Grass
7	Corn & Cichorium	Grass fallow
8	Sugar beets	Grass
9	Sugar beets	Grass fallow
10	Grass	Grass
11	Corn & Grass	Grass
12	Grass	Grass
13	Corn	Grass
14	Grass	Grass
15	Grass	Grass

References: Hallikainen, M. T., F. T. Ulaby, M. C. Dobson, M. A. El-Rayes, and L.-K. Wu, 1985: Microwave dielectric behavior of wet soilâĂŤ Part I: Empirical models and exper- ˇ imental observations. IEEE Trans. Geosci. Remote Sens., 23, 25–34, doi:10.1109/ TGRS.1985.289497.

References

Beven, K., Cloke, H., Pappenberger, F., Lamb, R. and Hunter, N.: Hyperresolution information and hyperresolution ignorance in modelling the hydrology of the land surface, Sci. China Earth Sci., 58(1), 25–35, doi:10.1007/s11430-014-5003-4, 2015.

Crow, W. T., Berg, A. A., Cosh, M. H., Loew, A., Mohanty, B. P., Panciera, R., De Rosnay, P., Ryu, D. and Walker, J. P.: Upscaling sparse ground-based soil moisture observations for the validation of coarse-resolution satellite soil moisture products, Rev. Geophys., 50(2), 1–20, doi:10.1029/2011RG000372, 2012.

Famiglietti, J. S., Ryu, D., Berg, A. A., Rodell, M. and Jackson, T. J.: Field observations of soil moisture variability across scales, Water Resour. Res., 44(1), 1–16, doi:10.1029/2006WR005804, 2008.

Hartemink, A. E. and De Bakker, H.: Classification Systems: Netherlands, in Encyclopedia of Soil Science, edited by R. Lal, pp. 265–268, Taylor & Francis Group, Boca Raton, Florida, USA., 2006.

De Lange, W. J., Prinsen, G. F., Hoogewoud, J. C., Veldhuizen, A. A., Verkaik, J., Oude Essink, G. H. P., Van Walsum, P. E. V, Delsman, J. R., Hunink, J. C., Massop, H. T. L. and Kroon, T.: An operational, multi-scale, multi-model system for consensus-based, integrated water management and policy analysis: The Netherlands Hydrological Instrument, Environ. Model. Softw., 59, 98–108, doi:10.1016/j.envsoft.2014.05.009, 2014.

Watanabe, K. and Flury, M.: Capillary bundle model of hydraulic conductivity for frozen soil, Water Resour. Res., 44(12), 1–9, doi:10.1029/2008WR007012, 2008.

Wood, E. F., Roundy, J. K., Troy, T. J., Van Beek, L. P. H., Bierkens, M. F. P., Blyth, E., De Roo, A., Döll, P., Ek, M., Famiglietti, J., Gochis, D., Van de Giesen, N., Houser, P., Jaffé, P. R., Kollet, S., Lehner, B., Lettenmaier, D. P., Peters-Lidard, C., Sivapalan, M., Sheffield, J., Wade, A. and Whitehead, P.: Hyperresolution global land surface modeling: Meeting a grand challenge for monitoring Earth's terrestrial water, Water Resour. Res., 47(5), 1–10, doi:10.1029/2010WR010090, 2011.

Wösten, J. H. M., De Vries, F., Hoogland, T., Massop, H., Veldhuizen, A., Vroon, H., Wesseling, J., Heijkers, J. and Bolman, A.: BOFEK2012, de nieuwe, bodemfysische schematisatie van Nederland, Wageningen, the Netherlands. [online] Available from: http://edepot.wur.nl/247678, 2013.